Choosing a Wind Power System

Ontario
Ministry of Energy
Honourable Philip Andrewes
Minister

Energy Ontario

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A HANDBOOK FOR POTENTIAL WIND POWER USERS

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ACKNOWLEDGEMENTS

FOREWORD

Virtually every aspect of modern life, from employment to transportation to the price of food, depends upon energy. Yet, the days of cheap and reliable supplies are over. Depletion of world fossil fuel reserves, price escalation, increased energy consumption and supply uncertainty have forced many nations to turn to alternative energy sources to meet their needs.

Like many other nations, Canada is taking steps to achieve greater energy self-sufficiency. The Province of Ontario plans to reduce its reliance on outside energy sources from the current 75 per cent to 63 per cent by 1995.

Windpower, one of the alternative energy sources receiving considerable attention, is particularly attractive because it is renewable, non-polluting and widely available for on-site generation.

The widespread use of windpower is currently limited by the relatively high cost of capital equipment. Improvements in windpower technology should reduce these costs in the near future. If fuel prices continue to rise, windpower will become more economically competitive. Some windpower applications in areas away from the grid or where fuel must be brought in by plane or boat, are already more economical than conventional power sources.

The Ontario Ministry of Energy has prepared this detailed handbook to help potential windpower users decide whether wind power is appropriate for them. It presents information in three sections: an overview of the state of the art, assessment of equipment needed and sample calculations. Numerous illustrations and tables are included.

If you require more detailed information on any topic, see the list of references included, or contact the Ontario Ministry of Energy at 56 Wellesley Street West, 11th Floor, Toronto, Ontario, M7A 2B7, 965-3246 (Toronto) or Zenith 0-80420.

PART ONE

INTRODUCTION

HISTORY AND RECENT DEVELOPMENTS IN WIND POWER

Although often referred to as "windmills", modern wind machines are far more sophisticated and adaptable than their relatively simple predecessors. The term "windmill" technically applies only to wind-powered machines used to grind grain and pump water.

We are all familiar with the English or Dutch windmills which can still be seen dotting the European and British countrysides. These picturesque, conical-shaped structures, characterized by huge vanes rotating on a horizontal axle were used almost exclusively for milling grain -- with one major exception. In the Netherlands, many were put to work pumping water during that country's period of great land reclamation projects.

These wind-powered mills quickly spread through coastal and open areas of Europe and North America. However, with the introduction of waterwheels and then steam engines in centralized flour mills, they fell into disuse during the nineteenth century.

The history of the technology of wind power reaches far back into history. People have been using the wind to power boats for more than five thousand years in China, Babylon and Persia, windmills harnessed the wind's energy more than two thousand years ago (Fig. 1).

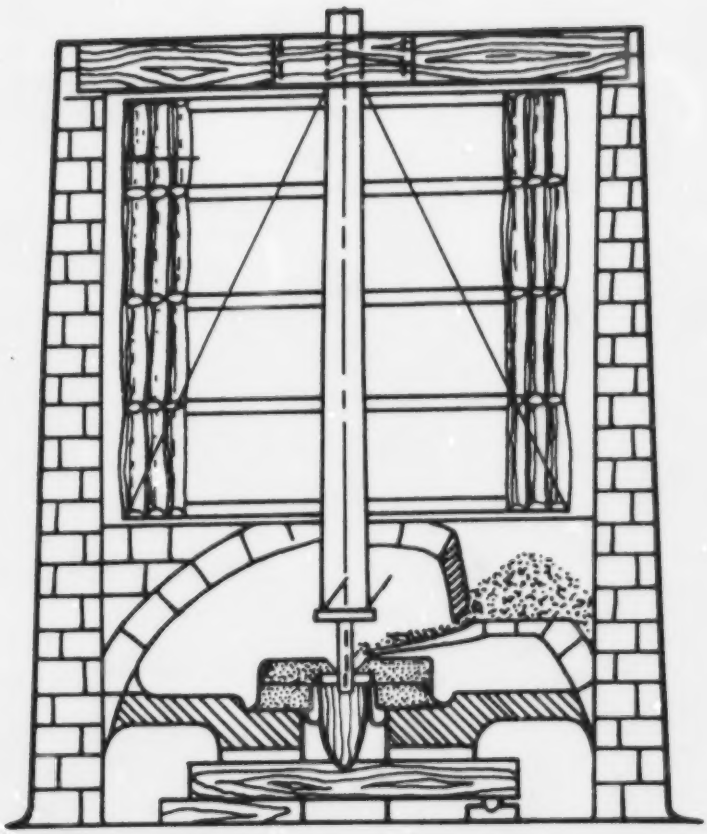


Figure 1 - This is a cross-section of a Persian vertical-axis windmill, 640 A.D. (Courtesy Van Nostrand Reinhold Co. - 1981)

Over the centuries various innovations gradually improved the windmill's efficiency. A major advancement was made with the development of the European post mill. An innovative machine, the post mill, which could be turned to face the wind, paved the way for its successor -- the tower mill. With its rotatable cap, the tower mill automatically changed to face the wind when the wind shifted (Fig. 2). The finest post mills were built in the Netherlands and provided both a livelihood and a dwelling for millers (Fig. 3).

North America witnessed a boom in the use of water-pumping windmills in the late 1860's. Most of them were multi-vaned and constructed of metal, with discs from 12 feet to 16 feet in length. The discs were cranked perpendicular to a tail vane which kept the blades facing the wind. The North American version of the pumping windmill reached its peak of popularity in the 1930s. After that date it was rapidly replaced by the electric motor.

Small wind generators were invented at about the same time to provide power for lights and radio receivers. In 1927, Marcellus Jacobs designed a very efficient wind generator which was widely used until the early 1950s. Access to convenient, low-cost power from power grid systems eventually rendered most windpower applications obsolete.

But the days of the wind machine are far from over. Two events have revived it -- unstable international crude oil prices and the refinement of the small, wind-powered electrical generator. Windpower can now be efficiently transformed into electricity, which in turn can be stored (usually with batteries) or used directly for many different purposes. Now windpower can be put to work even on the calmest days.

Figure 2 - This painting depicts
Tower mills and Post mills of the late
16th century, Strada

Windmills and Watermills by
John Reynolds

(Courtesy Praeger Publishers New York - 1975)

Figure 3 - This is a 15th Century Tower mill with stage (Stellingmolen) - The Falcon at Leiden

Windmills and Watermills by John Reynolds
(Courtesy Praeger Publishers, New York, 1975)

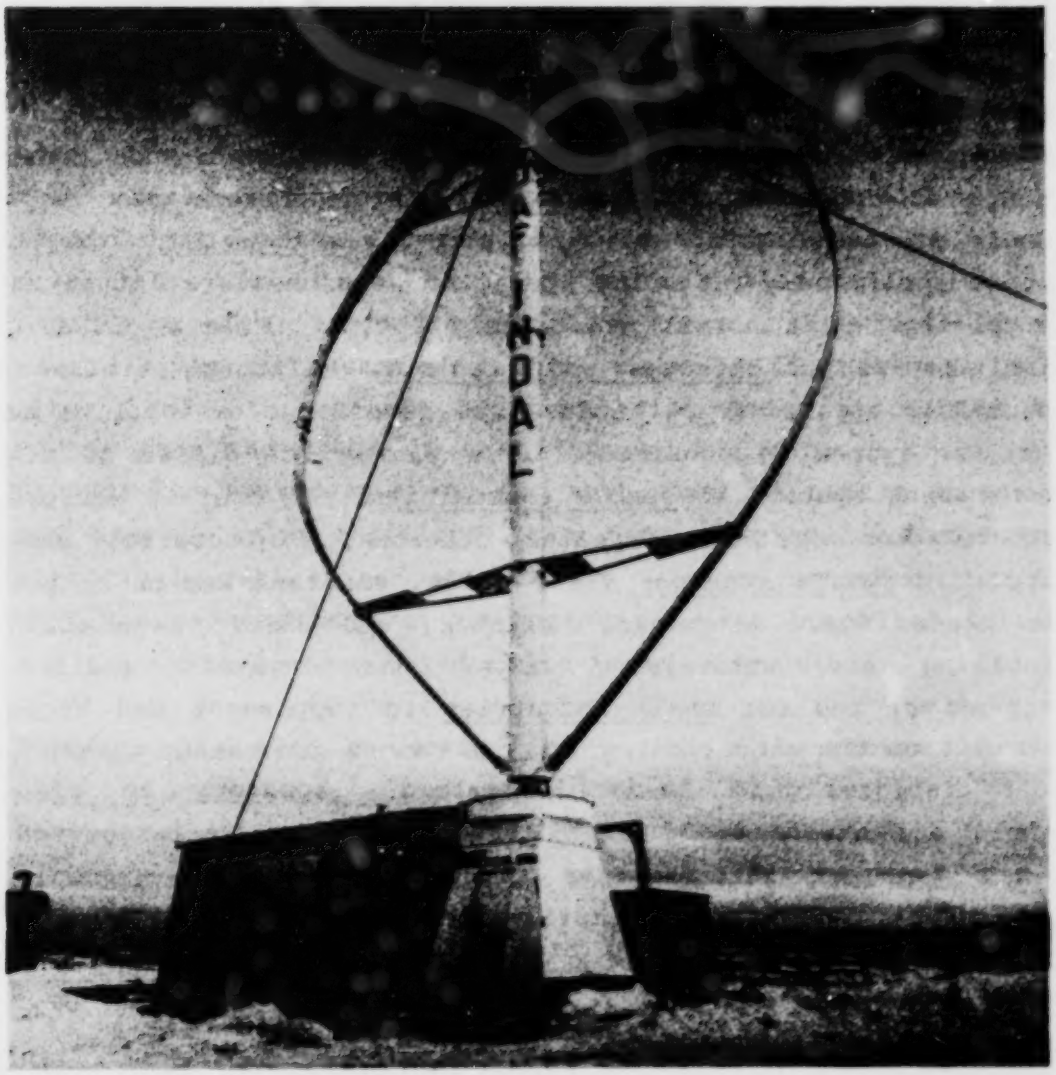
New terms are invented with new technology. Instead of "windmills" we have "wind turbines". The modern wind turbine is available in a surprising number of designs, and even more are being developed. One of the most exciting is the Darrieus vertical axis wind turbine, developed by the National Research Council of Canada. Coincidently, the Darrieus duplicates a design patented in 1927 by a French inventor. Prototypes of the Canadian Darrieus are presently being tested by manufacturers and government agencies in Canada and the United States.

Modern wind turbine generators can be divided into two types: large-scale high-technology installations which complement the national energy grid (with technicians on site); and small-scale, 'household' installations which are relatively simple and easy to repair and maintain. Discussion in this handbook is confined to the latter.

Further developments are expected from wind-energy testing programs in Canada. A computerized wind test facility has been set up by the Institute of Man and Resources on Prince Edward Island. In addition, experiments with combined wind-powered and diesel-powered generators for use in communities remote from the province's are being conducted by the Ontario Ministry of Energy, Ontario Hydro and several other Canadian institutions and agencies.

A 12 kW wind/diesel installation in Sudbury (see Fig. 4) has already demonstrated that significant fuel savings can be attained. A follow-up demonstration of 80 kW capacity in Sudbury, to show how it may provide electrical power for remote communities in windy areas, is currently being monitored. At the same time, the Atmospheric Environment Service of Environment Canada is analysing wind data to develop more precise methods of predicting winds and selecting sites.

Figure 4 - This is the Sudbury wind-diesel demonstration project.



MODERN WINDPOWER APPLICATIONS

Today's wind machines transform the wind's energy into either mechanical energy only or into mechanical and then into electrical energy. The mechanical power from the shaft of a wind turbine can be used for several purposes including pumping water for domestic consumption, fire prevention, irrigation and recreation; de-icing ponds to keep fish ponds open in the winter and maintain a sufficient oxygen supply; space or water heating by using devices such as mechanical "water churns".

Wind-powered electrical generators are used for a much broader range of applications. On farms wind generators can operate equipment for heating and ventilating; in households they can power appliances, including space and water heaters, often as a supplement to a normal electrical supply. Other applications include use in cottages and trailers, (although similar to household applications, because use is often occasional, a much smaller system is required); as a backup for diesel or other generating systems in remote communities; to operate equipment in telecommunications repeater stations, lighthouses, buoys, etc., in remote stations where a low, constant source of power is needed where winds are reliable, and where the staffing, fuelling and maintaining conventional systems would be expensive; and for small industries to supplement and augment power from the electrical grid or a remote generating station.

WIND TURBINES: TYPES AND OPERATION

There are two ways to extract mechanical energy from moving air: by slowing it down, causing 'drag' and by deflecting it, causing 'lift'. Drag is a force which works in parallel to the direction of the wind, while lift acts in perpendicular to the wind's direction. A turbine with blades which are pushed ahead by the wind uses drag and a turbine with blades which move across the wind uses lift (Fig. 5).

The blades of a drag turbine develop the most force because as they move with the wind the relative strength of the wind on them is reduced. Moreover, they cannot move faster than the wind itself as their force is derived from slowing the wind down. Drag turbines tend to be self-starting, slow, and capable of high 'torque' or twisting force. An example of this is the Savonius "bucket-shaped" turbine. Lift turbines, on the other hand, can operate at blade tip speeds which are much faster than the speed of the wind passing through them. They produce the most torque and the most power at higher speeds and are usually more efficient than drag turbines. Wind-powered electrical generators are almost always attached to lift turbines. Examples are the horizontal-axis propellor turbines and the vertical-axis Darrieus turbines (Fig. 6).

Turbines can also be classified by the orientation of their axis of rotation, "horizontal axis" or "vertical axis". Horizontal-axis turbines have to be aimed toward the wind or directly away from it while vertical-axis turbines can be powered by winds from any direction (Fig. 6).

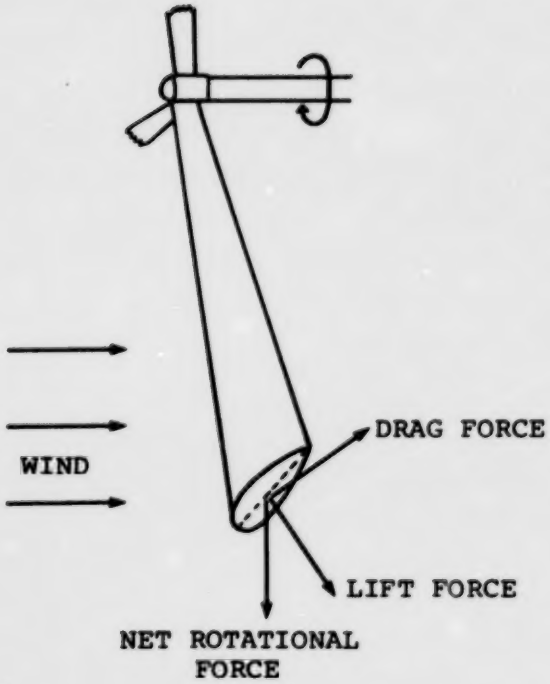
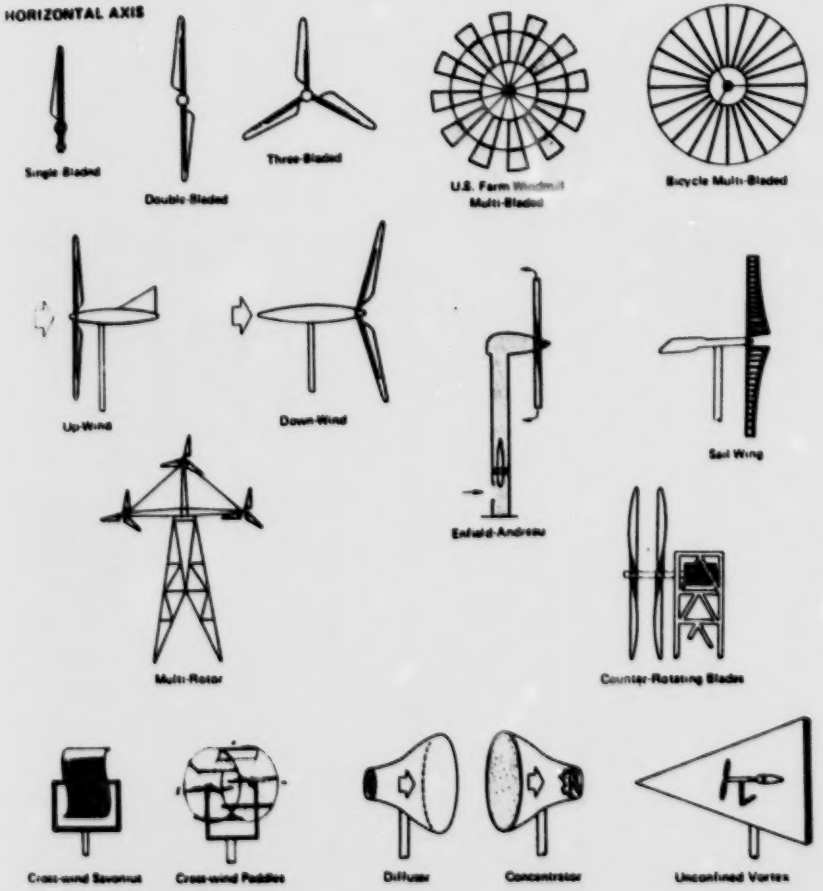


Figure 5 - This illustrates the forces on a rotor blade.



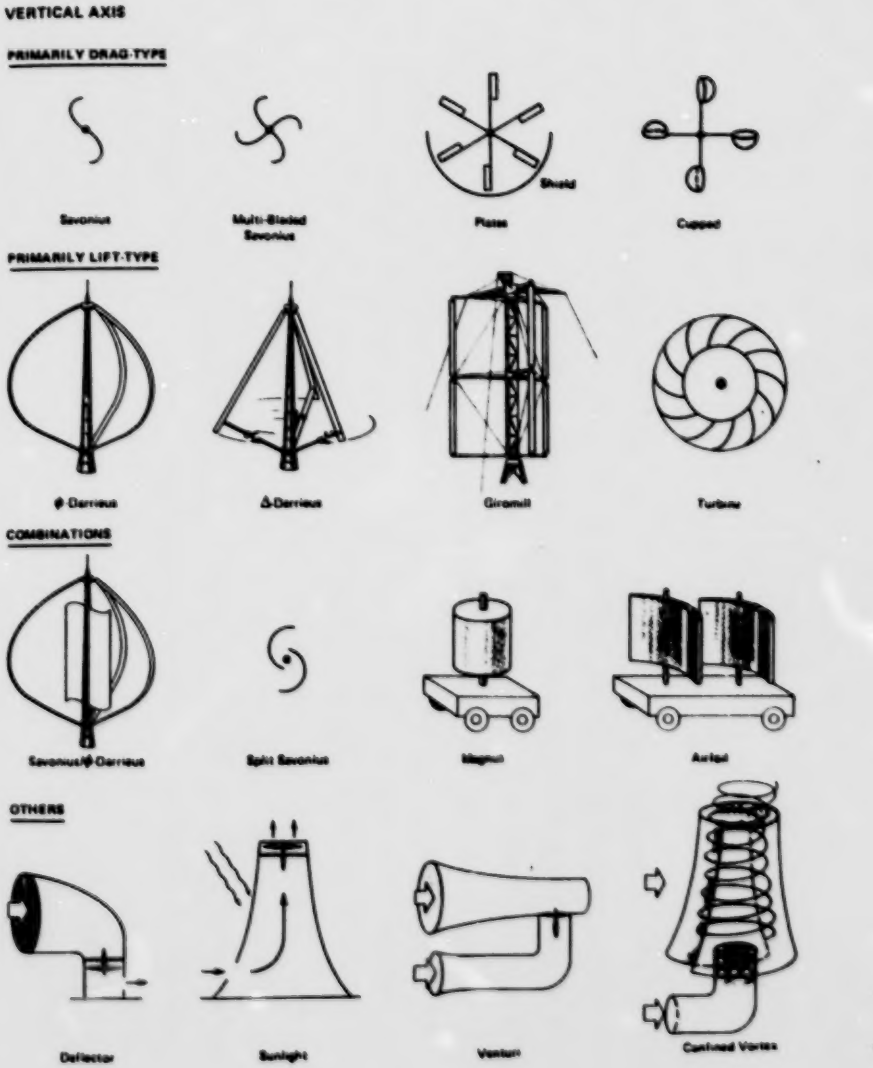


Figure 6: This illustrates the possible wind turbine configurations. (Courtesy - Wind Machines, 1980)

The force of the wind on a turbine varies in proportion to the area swept by the blades and the square of the wind speed. When the wind speed doubles, the force of the wind on a turbine therefore quadruples. But the power produced equals that force, times the wind speed, so that the power varies as the cube of the wind speed: when the wind speed doubles, the turbine can, in principle, produce eight times the power.

To limit the rotational speed and prevent damage in very high winds, many different governing devices are used. These include rotor tilt-back mechanisms (Fig. 7), 'feathering' mechanisms that twist the blade surfaces parallel to the wind and aerodynamic spoilers that intrude into the airstream over the blades, thereby destroying lift and increasing drag. Friction brakes are often used in extreme winds to shut down turbines.

The wind turbine is only one part of a wind energy system whose purpose is to perform a task. Other parts of the system have to be selected along with the turbine, and the size of the system as a whole is governed by the amount of work it must do. This section discusses the components for three systems: a wind-powered electrical generating system to operate appliances and equipment, a "wind furnace" for space and water heating, and a wind energy system dedicated to pumping water. Methods for sizing the turbine and its components are presented in Chapter 2.

ELECTRICITY GENERATION WITH WIND POWER

There are two types of wind-generation systems, "independent" and "dependent". An independent system has its own energy storage facilities and does not need to be connected to any other energy source. A dependent system operates only in connection with another source of electricity such as a diesel generator or an electrical grid.

Figure 7 - Rotor tilt-back method for governing blade revolutions in high winds.

Courtesy L & R Broadcast Services, Oakville.

AC versus DC

The components required for any of these systems depend on what form of electricity is required: direct current (DC) or alternating current (AC). Batteries store only DC. In North America, however, most appliances and equipment are designed to use AC at 60Hz (cycles per second), though heating elements and incandescent lightbulbs can usually use either type. Fortunately for our purposes, DC can be converted to AC by means of an 'inverter', while AC can be changed to DC by means of a 'rectifier'. An AC generator (or 'alternator') with an attached rectifier can produce DC current, just as a DC generator with an inverter can produce AC.

Independent and Dependent Systems

The simplest independent system is a wind generator with DC output linked to a battery storage system which powers DC appliances. However, many systems will also incorporate a stand-alone inverter to run the standard household appliances on 60 Hz AC. The independent system is best applied in remote locations.

A dependent system couples to the local grid and uses this grid to maintain the AC output at the standard 60 Hz frequency and voltage and to act as a combined storage and backup medium. An induction or synchronous generator may be coupled directly to the grid, or a DC generator may be coupled via a synchronous inverter. A dependent system relies on the grid and therefore cannot function if the grid power fails.

To make use of the advantages of both independent and dependent systems, a combined system is also possible. Such a system may utilize battery storage and a dual function inverter which can operate both when connected or disconnected from the grid power line.

Storage Capacity and Utility Backup

The storage capacity, which confers independence on an electrical wind system, is the second major cost component after the wind generator itself. Its main function is to provide power when the wind is not sufficient to enable the generator to meet the demand. A secondary function is to help absorb surplus power and store it for later use. When the generator is developing more energy than is being consumed, the excess must be directed somewhere to protect the turbine and generator from overspeeding and overheating. Charging the batteries is the first recourse. After the storage is fully charged, either the turbine must be shut down or the excess must be 'dumped', i.e. shifted to some piece of equipment such as a water-heating or space-heating element that can absorb surplus power indefinitely.

At this point the advantage of interconnection with another electrical system such as the provincial grid, can be seen. Not only can such a source provide backup power in place of storage but it can also accept surplus power. Ontario Hydro, for example, will arrange to buy and to sell electricity with such an interconnected wind system. Appropriate safety measures and in-flow and out-flow electrical meters are required.

There are a wide variety of batteries available at varying prices depending on storage capacity and cycle lifetime. The three commercially-available battery types suitable for wind energy applications are lead-acid, nickel-iron, and nickel-cadmium. Lead-acid batteries, the most commonly used, tend to be less expensive than the others but have a lower storage efficiency, particularly in cold temperatures. However, new modifications to lead-acid batteries incorporating antimony or calcium now allow a deeper discharge, a seven or eight-year life cycle, more than 90 per cent efficiency and a lower freezing point.

Nickel-iron batteries last much longer and are more efficient but allow a considerably lower level of output current. Nickel-cadmium batteries have long lifetimes and are very efficient at a wide range of temperatures, but they are expensive. Many advanced battery designs are now under development. Some may be available by the late 1980s.

An important consideration in a wind energy system is situating the batteries. Owing to the decline in efficiency in cold temperatures, batteries should be protected from such extremes. Indoors in a shed or basement is a good place. Batteries produce flammable hydrogen gas in small quantities and therefore adequate ventilation is essential.

Heating

In Ontario, the coldest months of the year are also the windiest. The chill factor of the wind itself is often a significant additional drain on heating facilities. The use of wind energy for heating is therefore an attractive notion. The addition of electrical space heaters or heat pumps to the list of appliances supported by a wind energy system, however, will greatly enlarge the size of the system required, particularly the amount of costly electrical storage capacity.

Instead of using battery storage capacity to handle heating, a more feasible alternative is to store the energy as heat itself in a specially-constructed heat reservoir. The reservoir may be of water, stone, concrete, or various other substances suited to storing heat either by a simple increase in temperature or by a change of state from solid to liquid or from liquid to gas.

An estimate of the size and cost of such a heat storage reservoir would be based on heat demand, climatic data, building construction, characteristics of the storage medium, and other technical information not considered in this handbook.

Water Pumping

The essential components of a water pumping system are the turbine and tower, the pump and piping, and one or more water storage reservoirs. The size of the reservoir depends on how the water is to be used. The pump may be electrical and connected to a turbine-generator or it may be mechanical and connected to the turbine shaft through a gear box. A purely mechanical system would depend on the suitability of a common location for the turbine and the pump.

In addition to the energy required to lift water, energy is also needed to push it through pipes. This energy, which must be supplied by the pump, is called the 'equivalent head loss' and plays an important part in determining the size of system required.

INSTALLATION AND UPKEEP OF A WIND ENERGY SYSTEM

Impact on Surroundings

Although the environmental impact of wind machines is relatively low, there are a number of considerations of which the potential user should be aware. In operation, wind turbines make a noise - a combination of aerodynamic and mechanical sounds. The effect can be kept to a minimum by placing the machine at a distance from dwellings. Large size turbines have also been known to affect radio, television, and radar reception, and to produce reverberations in nearby buildings.

Some people find wind machines visually unattractive or feel that such machines pose a threat to their personal safety or to their property value. The potential user should seek the opinions or approval of neighbours before installing a wind energy system.

Maintenance and Safety

A wind energy system cannot be installed and then ignored. The user must be prepared to undertake scheduled maintenance, which involves periodic oiling and greasing, as specified by the manufacturer. Components should also be inspected regularly for evidence of wear, metal fatigue, or other problems. Occasional replacement of some parts, such as blades, is normal. Batteries and inverters require regular checking as well. In addition to routine inspections, equipment exposed to storms should be inspected immediately afterwards.

Like any other machine, wind turbines sometimes fail or break down. This can be particularly hazardous since catastrophic failure could result in the tower and turbine toppling over or in the throwing of a blade. The turbine should therefore be erected in an area which is clear of other structures.

Towers

The tower used to support the wind machine must be designed to hold its dead weight and to withstand the lateral drag force caused by high winds. Wind turbine manufacturers will usually specify a particular type of tower for their machines, but the user should always take the precaution of consulting the manufacturer on tower specifications anyway.

The tower must be firmly anchored to the ground at its base or be supported with guy wires. Soil conditions should be checked with the local county agent, and the foundation constructed according to local building codes and to the manufacturer's specifications.

Tower height should be determined in part by consideration of the difficulties associated with setting up higher towers. Most wind turbines need a block-and-tackle or a crane to lift them to the top of the tower. It is possible to install the machine on the tower and then erect both, but this can be a dangerous practice, particularly in the case of heavier machines. (Some newer towers are being designed to tilt-down, thus eliminating the need for a crane.)

Both tower and turbine must be protected against lightning strikes. This is done by connecting the metal structure of the turbine to buried water pipes, to stakes driven in the ground, or to buried metal sheets via a heavy cable capable of carrying a large current.

Weather Hazards

High Winds: Wind turbines usually have a 'survival speed', the maximum wind speed they can withstand without experiencing premature wear or structural damage. An estimate of maximum gust speed for a given location can be made from available wind data (Table 3). On occasions when extreme winds are expected, the turbine should be shut down and locked with the brake.

Freezing Rain and Heavy Snow: These conditions can cause stress and vibration in the turbine if ice and snow accumulate inside exposed machinery and gears; it may be necessary to enclose all rotating machinery or to install a de-icing device or vibration shutdown controls.

Extremely Cold Weather: Cold temperatures can impede mechanical operation by causing lubricating oil to thicken necessitating lighter oil or even occasional heating of the oil. Batteries and most electrical components are also affected by cold temperatures and should be located in insulated enclosures.

Lightning: Lightning protection equipment must be installed on all systems.

Salt Spray, Blowing Dust, and Hail: These conditions can cause corrosion and damage, raising repair and maintenance costs. Protective measures are needed in such environments.

Grid Connection

The following regulations apply to the installation of a grid-connected wind generator in Ontario. The rules for other jurisdictions in Canada are similar.

- The local utility must be notified and its approval must be obtained before the system can be installed. One requirement will be the installation of a transfer switch between the wind generator and the utility line to disconnect the two automatically whenever there is a power failure on the line, thus protecting line maintenance crews.
- The equipment installed must be approved by Ontario Hydro or the Canadian Standards Association.
- When complete, the installation must be inspected and approved by the Ontario Hydro Inspection Department.

SITING THE WIND MACHINE

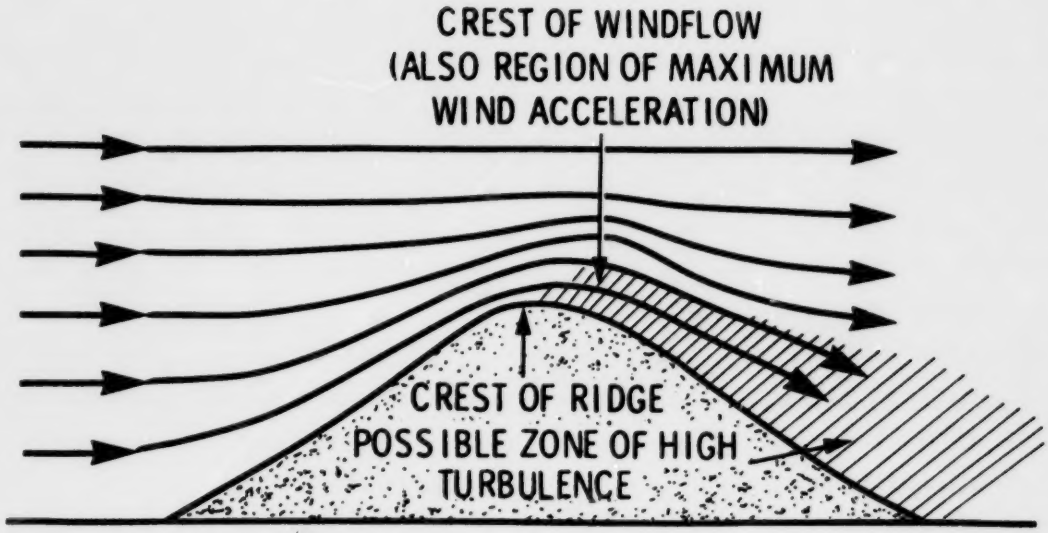
Wind is caused by a horizontal difference in pressure in the atmosphere and the general effect of the ground is to retard it. As a result, winds are usually stronger aloft than at ground level. The retarding effect is present even over water, but it is much more pronounced over wooded or built-up areas, and it varies with the terrain and land cover. Over flat fields with crops, for example, the wind speed would be 42 per cent higher at 30 m than at 6 m, so that the same wind turbine could produce up to three times as much power at the higher level than at the lower one. In wooded areas the difference in wind speed between those heights is about 57 per cent, so that the difference in power output could be fourfold. (The wind speed calculations are based on the coefficients presented in Table 4). Generally speaking, therefore, the higher above the ground a turbine is positioned, the more power it will produce and the increase will be more pronounced the rougher the terrain.

Overall, the effect of the ground is to slow down the wind, but under certain circumstances, it may actually accelerate it. Wind accelerates when it flows over a ridge or an elongated hill, so that such a site may be excellent for a turbine (Fig. 8). Sites on ridges avoid the periods of calm that occur in valleys. However, a ridge which is not perpendicular to the prevailing wind will lose much of its effectiveness as a site. Turbines should be located at the summit of a ridge, or slightly below the summit on the upwind side (upwind in relation to the prevailing winds).

The acceleration of wind over a hill or a mountain is less pronounced than that over a ridge because the air tends to flow around rather than over it. Side slopes may well be best in such situations.

Figure 8 - This illustrates acceleration of wind over a ridge.

(Courtesy - Siting Handbook, 1978)



Cliffs enhance wind speed, although right at the edge there may be severe turbulence and wind shear (a sharp gradient in the speed or direction of the wind). The best sites will be found back from the edge somewhere between one-quarter and 2-1/2 times the height of the cliff (Fig. 9).

Valleys, gorges, passes, and saddles in hilly areas can be good sites because of their funnelling effect on the wind. But conditions in them can be very sensitive to the direction of the wind, so that if the prevailing wind direction is not strongly predominant, they may act as obstructions. Furthermore, wind passing through them is prone to turbulence and shear, both of which can strain a turbine.

Because large lakes minimize wind resistance, a lakeshore site can be excellent, especially on an exposed peninsula. Trees may obstruct offshore and onshore breezes and can sometimes eliminate the advantages to be gained from lake to land breezes (Fig. 10).

Many sites cannot avoid obstructions altogether (Fig. 11). Therefore, the following rules should be observed when locating near building-like obstructions.

- discover the direction of the prevailing winds (in Ontario they are generally southwesterly in summer and northwesterly in winter);
- site upwind a distance at least twice the height of the tallest building, measured from the nearest building;
- site downwind at least 10 times the height of the tallest building measured from the nearest building;
- mount the turbine at least twice the height of the tallest building when very close to buildings.

A row of trees may have a greater downwind effect especially if the foliage is of medium density.

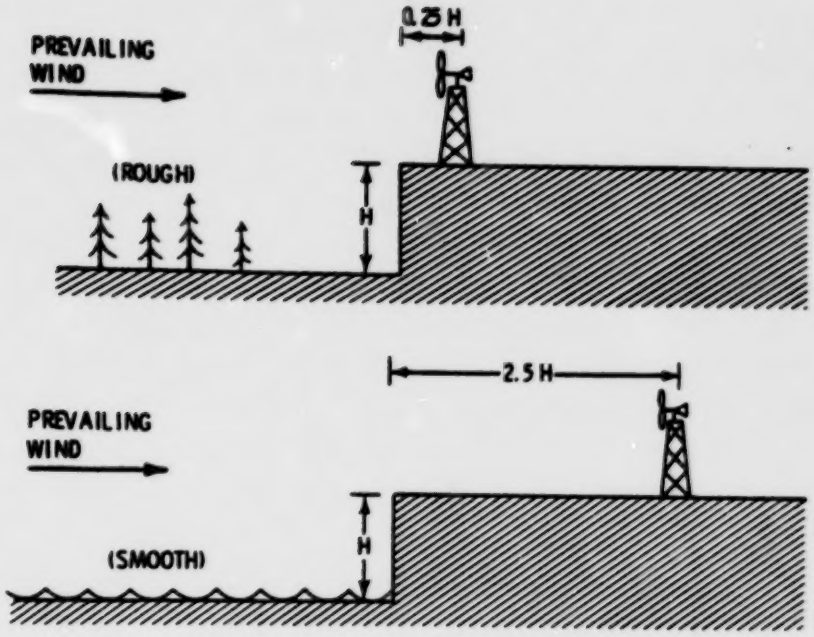


Figure 9 - This illustrates the effects of upwind roughness on the locations of the best site downwind from a cliff. (Courtesy U.S. Department of Commerce)

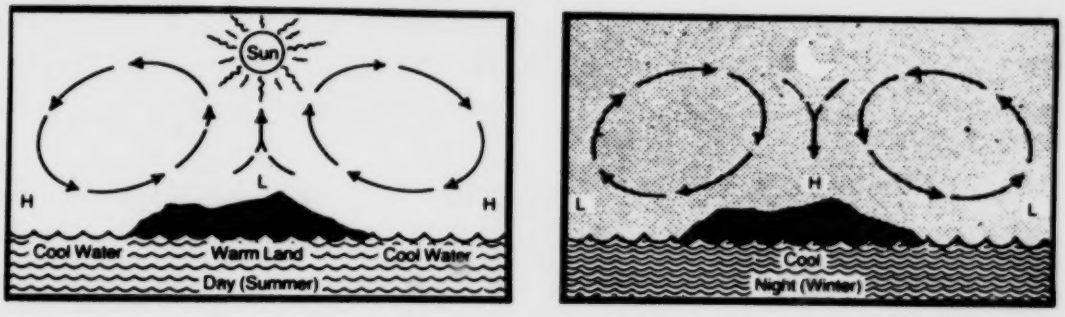


Figure 10 - This illustrates land lake breeze patterns. (Courtesy - Wind Energy, 1979)

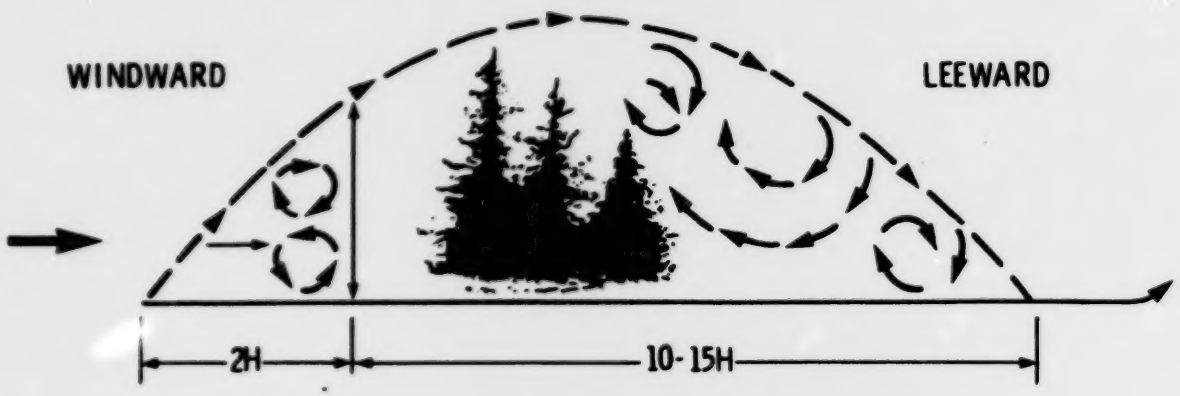


Figure 11 - Airflow near obstructions -
(Courtesy U.S. Department of Commerce)

The proposed site should be checked for turbulence in various wind conditions. A convenient way of doing this makes use of a kite or a lighter-than-air balloon. Two strings are tied to the kite or balloon, a primary one to hold it in position and a secondary one intended to drop vertically over the site and be anchored to the ground. Lengths of ribbon are fastened at regular intervals along the secondary string. When the kite or balloon is raised into position so that the secondary string with its floating ribbons descends vertically where the tower is planned, the degree of turbulence at various heights can be observed by the degree of flapping of the ribbons.

Distance from Turbine to Point of Consumption

Direct use of the mechanical energy of a wind turbine is possible only where the turbine site is very near the point of consumption. The use of the turbine to generate electricity makes possible much more remote siting, but the prospective user must be alert to the problem of transmission line losses of power and voltage drops.

The installation of a wind electrical system should comply with the Canadian Electrical Safety Code, which stipulates that the voltage drop from the point of generation to the point of end use cannot exceed five per cent.

The calculations involved are described in the next part of this handbook under Power Transmission Losses.

PART TWO

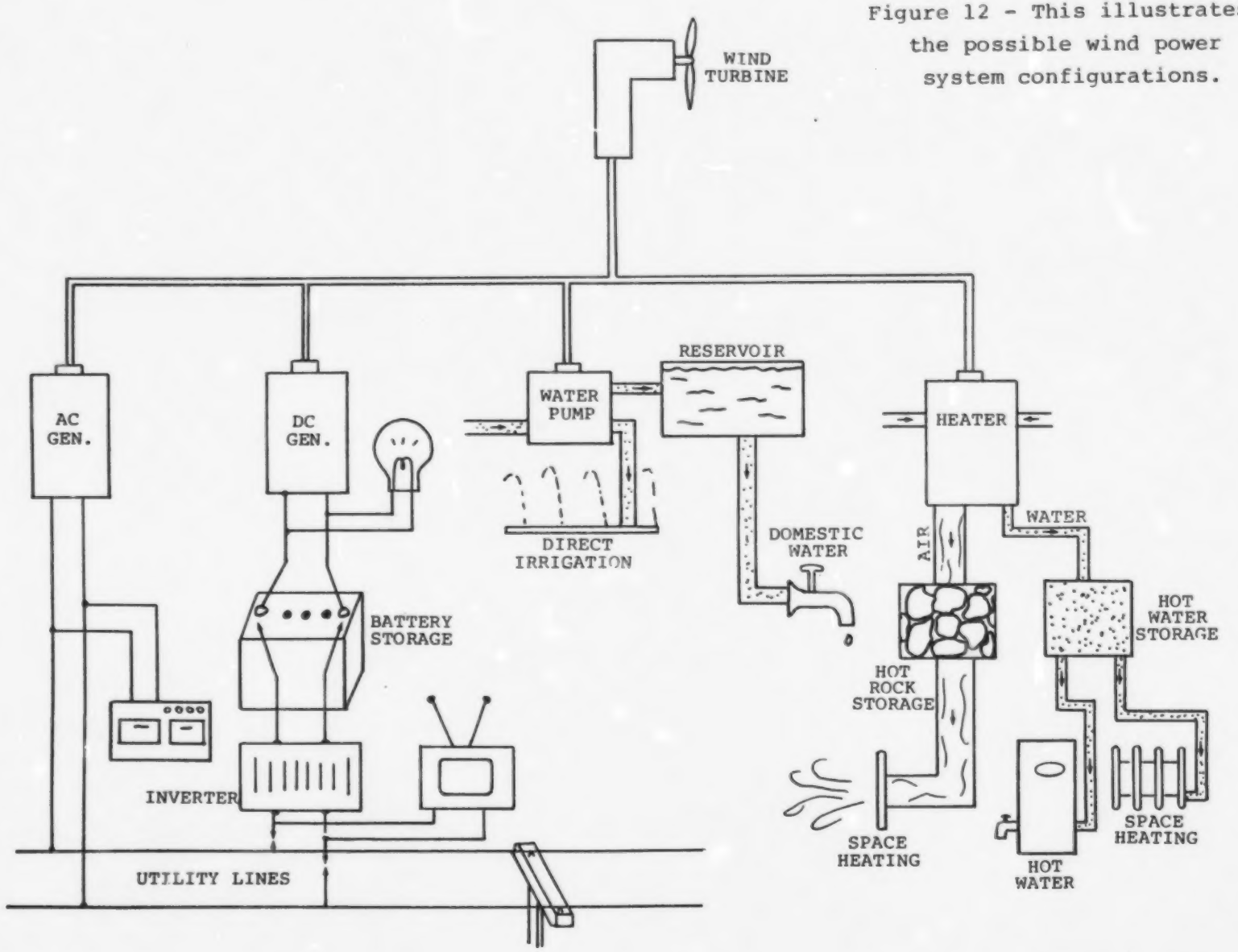
HOW TO PLAN AND SIZE A WIND ENERGY SYSTEM

Let us say the potential user has in mind a possible use for a wind energy system (see figure 12). Before you can proceed with an installation you must estimate the size of the system required and how much it will cost. This part of the handbook will help in these calculations.

The commercially available components of a wind energy system vary so much in efficiency and cost for a given output that it would be seriously misleading in many cases to present even rough overall estimates here. Furthermore, whatever may be said about wind conditions across Ontario, the peculiar characteristics of a specific site, the particular energy consumption pattern in question, and the sometimes decisive influence of a single technical variable such as the height of the tower, make an individual evaluation indispensable.

What this means is that one must begin by obtaining information from wind turbine manufacturers on a number of different machines. Sometimes this information is in brochures or catalogues and sometimes it can be acquired over the telephone. When those data have been gathered, this handbook will help in making estimates. With certain further information on wind conditions obtained from Environment Canada, or better still from systematic readings on the site itself, one can refine the estimates and, if going ahead, prepare for installation.

Figure 12 - This illustrates the possible wind power system configurations.



Two Examples

To establish a range of candidate machines, obtain a general idea of the size of wind turbine needed. The crucial factor here is the amount of energy required, and we shall now consider how to estimate this in two cases. The first case is a remote farmhouse unconnected to the electrical grid. An independent wind energy system is to be evaluated for the operation of domestic appliances. The components will be a wind generator (DC), a tower, a stand-alone inverter, and a battery storage system. The second case is a wind-powered water pump.

CHOOSING AND SIZING A WIND/ELECTRIC GENERATION SYSTEM

Calculating Power Demand and Energy Needs

We need to know both how much work the energy system has to do and how fast it must do it. The former governs the size of the whole system and is measured as annual energy consumption while the latter affects the size of energy converters within the system and is measured as maximum power demand. The first step in selecting a wind energy system is, therefore, to establish how much power and energy will be required from it.

To clarify the difference between energy (a measure of work done) and power (the rate at which energy is consumed), consider an energy system designed to operate a lightbulb with a power of 40 watts. In one hour such a bulb consumes (i.e. converts to light and heat) 40 watt hours of energy; in one hundred hours it consumes 4000 watt hours, or 4 kilowatt hours (kWh), of energy. If the bulb was on for half of the 8760 hours in a year, its annual consumption would be (4380 times 40/1000) 175.2 kWh. Consequently the energy system would have to be able to deliver 40 watts of power and 175.2 kWh of energy a year.

Maximum Power Demand

Consider the maximum number of appliances that could be operating simultaneously. This might well occur on a winter evening when such appliances as a furnace, water heater, stove, and lights are all operating at once. Next, add up their power needs, taking each from the appliance's nameplate or from the general list in Table 1. The total is the maximum power the system must be able to provide for end use.

In the interests of utilization and economy, consideration should be given to arbitrarily restricting demand to match the output of a smaller system.

Annual Energy Consumption

The simplest way to determine annual electrical consumption is to consult previous hydro bills. But in many new and remote locations, such simple indicators do not exist.

Here are two alternative methods. Table 1 gives a range of consumption values for a variety of appliances. Take a lower value if the appliance is smaller than average or use is lighter than normal, and conversely take a value towards the upper end of the range if the appliance is a large one and gets heavy use. The total is an estimate of annual energy consumption.

Table 2 outlines a more detailed calculation, in which is listed the nameplate power from each appliance. Multiply it by the average daily use in hours for each month, and add up the months to reach an annual total.

TABLE 1

Power Outputs and Annual Energy Consumption of Typical Household Appliances

Appliance	Power (watts)	Annual Energy Consumption (kWh)
Air conditioner (window)	1600	1,392 - 5,640
Blender	200 - 600	12 - 36
Car block heater	300 - 450	720 - 1,620
Clock	2	12
Clothes dryer	4,600 - 6000	1,044 - 3,600
Coffee maker	800 - 900	120 - 168
Electric blanket	100 - 200	180 - 192
Electric heating (baseboard)	6,000 - 10,000	18,000 - 19,200
Exhaust fan (kitchen)	200 - 250	96 - 168
Freezer (chest, 15 cu. ft.)	350 - 440	1,008 - 1,380
Hotplate (1 burner)	500 - 1200	84 - 144
Humidifier	180 - 500	60 - 180
Iron	1,000 - 1,500	144 - 216
Kettle	1,000 - 1,200	120 - 480
Lights		
- each 60 watt	60	60 - 84
- each 100 watt	100	108 - 144
- each 4 ft. fluorescent	50	72 - 144
Microwave oven	1,400 - 1,500	168 - 180
Mixer	125	12
Oil burner	100 - 400	300 - 480
Portable electric heater	660 - 2,000	360 - 2,400
Radio (solid state)	50 - 70	72 - 96
Range (top only - 4 burners)	6,000	720 - 1,440
Range and oven	7,200	1,200 - 1,800
Refrigerator (14 cu. ft.)		
- standard	300 - 330	720 - 1,140
- frost-free	360 - 615	1,800 - 2,160

Appliance	Power (watts)	Annual Energy Consumption (kWh)
Sewing Machine	100	12 - 24
Stereo (solid state)	30 - 100	48 - 144
Shop tools		
- 1/4 in. drill (1/6 hp.)	250	12 - 60
- skill saw (1 hp.)	1,000	60 - 72
- table saw (1 hp.)	1,000	36 - 48
- lathe (1/2 hp.)	460	12
Toaster	1,100	36 - 60
Television Set		
- black and white	50 - 250	84 - 360
- colour	200 - 350	300 - 528
Washing machine (15 loads/month)	290 - 700	96 - 132
Water heater		
- 30 gal.	1,200	1,284 - 2,040
- 40 gal.	2,000	2,148 - 3,360
- 50 gal.	3,000	3,432 - 5,040
Water pump	420 - 460	60 - 240
Vacuum Cleaner	630 - 750	48 - 96

SOURCE: Ministry of Energy

TABLE 2

Detailed calculation of maximum power demand and annual energy consumption

---

1. Determine the power rating of each appliance (Read nameplate value of use Watts = Volts x Amperes where voltage and current are on the nameplate. Where power is given in HP, use 1HP = 846 W).

   _____ kWh

2. Calculate maximum power demand by deciding which appliances may be on all at once and adding their power ratings.

   _____ kWh

3. Determine time intervals per month for which each appliance is on and multiply by its power rating to give monthly energy consumption per appliance.

   _____h X _____kW = _____ kWh

4. Add up energy consumed by all appliances to give total monthly energy consumption.

   _____ kWh

5. Add up monthly energy consumptions to give annual energy consumption.

   _____ kWh

Average Power Demand

Divide the annual energy consumption by 8760, the number of hours in the year, to find the average power in kilowatts. This fundamental number represents the theoretical minimum power the system must be able to produce for end use on a continual basis to satisfy the annual energy consumption. With some adjustments it will be compared to the average power supply available from a given wind turbine in a given environment.

Preliminary Sizing of Wind Generator and Selecting Tower Height

Average Power Production Required

We have estimated the average power demand. The inverter itself will absorb some power on top of that. In the absence of a manufacturer's specification, we may assume the inverter's efficiency to be about 90 per cent. Thus we have to raise our estimated needs as follows:

Real average power demand = average power demand x 1.10. We should add a safety margin of at least 10 per cent and perhaps as much as 60 per cent, depending on how insecure our estimates of wind and power demand seem (a typical safety margin at this point is 20 per cent).

Average power production required (Pa) = real average power demand plus safety margin.

This number (Pa in kW) is the key to evaluating wind turbines.

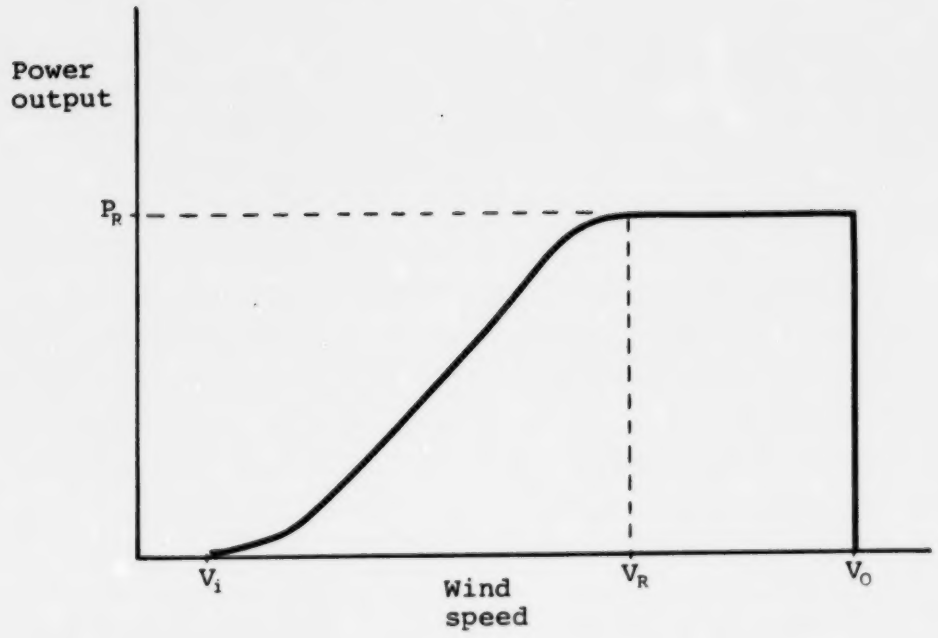
Information From Manufacturers

The candidate wind generators on which information is gathered should have rated power outputs of between 3Pa and 8Pa.

The manufacturer can often provide a wind speed/power output curve for a wind generator. The technical information needed for preliminary estimates can be taken from such a curve, and the meaning of the terms used is best shown by examining a sample curve (Fig. 13.)

The sample machine power curve shows that as the wind speed increases from zero, a point is reached when the generator begins to operate (Vi, cut-in speed), after which power output increases rapidly with wind speed to a maximum (Vr, rated wind speed, giving Pr, rated power). Following this point, power output is fairly constant as wind speed increases until a point is reached (Vo) when turbine and generator are shut down to prevent damage to the mechanism. With the curve, it can be seen immediately the wind speed needed to produce a given power output as well as the power output for a given wind speed.

The data needed for preliminary evaluation of a wind generator, whether taken from such a curve or obtained separately from the manufacturer, are Vi, Vr, and Pr.



Symbols: Pr - rated power
Vi - cut-in wind speed
Vr - rated wind speed
Vo - shut-down wind speed

Figure 13: Typical wind speed/power output curve of a wind turbine.

Estimate of Annual Mean Wind Speed

The preliminary evaluation for wind generators requires only the annual mean wind speed (Vm) at the site. An estimate can be made for a site in Ontario based on meteorological data presented in this handbook. Eventually it would be advisable for a prospective wind machine purchaser to have this estimate checked by wind recordings made on the spot. Techniques for doing this are discussed in Appendix B.

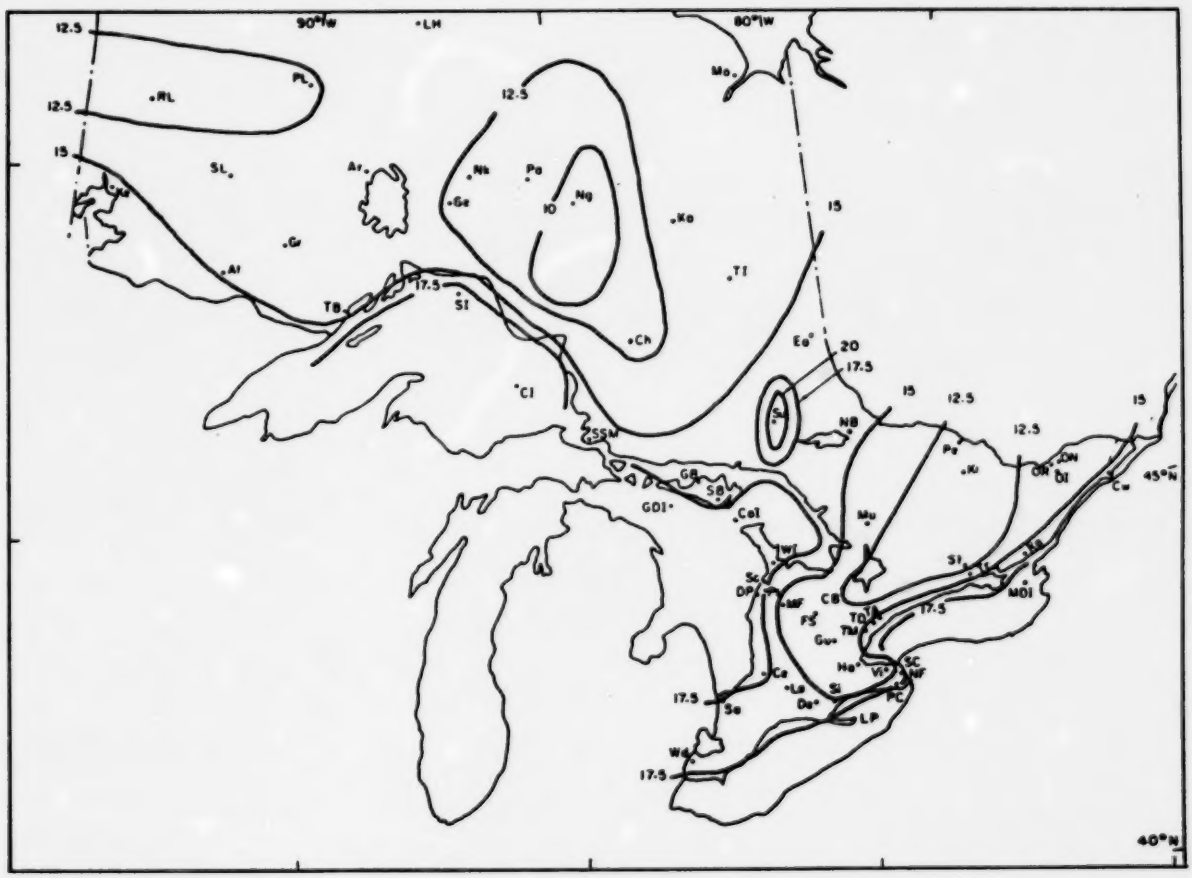
From Table 3 select two or three nearby meteorological stations and note the annual mean wind speed and the station heights. Estimate Vm at the site at a given height, crosschecking against the mapped contours in Figure 14. The degree of deformation of conifers can provide another cross-check (Fig. 15). Note that Table 4 gives coefficients for extrapolating wind speed from one height to another in different terrains, based on the fact that winds are lighter near the ground.

Comparing Wind Generators

The annual mean wind speed at a certain height at the site (Vm) is known, as well as the average power production required (Pa). Moreover, for several wind generators whose rated power outputs range between 3Pa and 8Pa, Vi, Vr, and Pr have been found. Now use Figure 16 to find the tower height needed for each machine to produce Pa.

For each machine, Vi/Vr specifies a curve between those shown on the figure. Pa/Pr gives a point on the vertical axis. Where a horizontal line from this point (Pa/Pr) intersects the curve in question, a vertical line dropped from this intersection point crosses the horizontal axis at a point called Vr/Vmreq.

Figure 14 - The map shows Isovents of annual mean wind speed in Ontario in km/h. The contour lines connect sites with the same annual mean wind speed; To find wind speeds between the contours, interpolate accordingly.



(Courtesy Environment Canada)

Figure 15 - This Illustrates deformation of conifers as an indication of probable annual mean wind speed range in km/h. These data using the Griggs-Putnam Index of deformation were prepared by E.W. Hewson, J.E. Wade, and R.W. Baker of Oregon State University - (Courtesy U.S. Department of Commerce).

TABLE 3 continued

Ontario wind data

Station Name	Abbreviation on Map	Terrain Category	Anemometer Height (m)	Annual mean wind speed (km/hr)	Annual mean wind speed at 30m height (km/hr)	Maximum gust speed (km/hr)
Armstrong (A)	Ar	E	25	12.6	13.3	95.0
Atikokan	At	E	13	7.7*	9.7*	83.7
Camp Borden	CB	E	18	10.1	11.7	66.0
Centralia (A)	Ce	C	20.5	18.7	19.9	157.8
Chapleau	Ch	E	13	11.3	14.3	104.7
Cornwall	Cw	D	22	16.7	17.9	90.2
Delhi	De	D	10	9.7*	12.4*	74.1
Douglas Point	DP	D	12	18.8	23.0	109.5
Earlton (A)	Ea	A	19.5	16.1	16.7	144.9
Fergus (Shand Dam)	FS	D	13	14.2	17.1	95.0
Geraldton	Ge	D	12.5	12.1	14.7	99.8
Gore Bay	GB	C	10	16.4	19.6	125.6
Graham (A)	Gr	E	16	14.2	16.9	101.4
Guelph	Gu	E	10	13.8	18.8	111.1
Hamilton (Marine Police)	Ha	D	15	14.8	17.2	107.9
Hamilton (RBG)	Ha	E	17.5	12.7*	14.8	95.0
Kapuskasing (A)	Ka	E	19	14.3	16.3	104.7
Kenora (A)	Ke	E	10	16.0	21.8	128.8
Killaloe	Kl	D	17.5	11.6	13.1	125.6
Kingston (A)	Kg	C	10	16.9	20.1	122.4
Kingston (Marine)	Kg	C	13.5	16.6	18.9	112.7

TABLE 3

Ontario wind data

Station Name	Abbreviation on Map	Terrain Category	Anemometer Height (m)	Annual mean wind speed (km/hr)	Annual mean wind speed at 30m height (km/hr)	Maximum gust speed (km/hr)
Lansdowne House	LH	E	13	14.8	18.7	90.2
London (A)	Lo	C	10	16.4	19.6	122.4
Moosonee	Mo	E	10	13.4	18.2	98.2
Mount Forest	MF	D	10.5	14.8	18.6	112.7
Muskoka (A)	Mu	D	27	13.7	14.0	120.8
Nagagami	Ng	E	13	7.4	9.4	54.7
Nakina (A)	Nk	E	16	12.4	14.8	133.6
Niagara Falls	NF	-	-	15.4	-	130.4
North Bay (A)	NB	D	13	15.3	18.4	90.2
Ottawa (Int. A)	OI	C	10	14.9	17.7	135.2
Ottawa (NRC)	ON	D	14.5	11.7*	13.7*	75.7
Ottawa (Rockcliffe A)	OR	D	15	13.8	16.1	161.0
Pagwa (A)	Pa	E	13	11.3	14.3	104.6
Paisley	Ps	C	10	13.5	16.1	88.5
Petawawa	Pe		30.5	10.8	10.8	90.1
Pickle Lake	PL	C	10.5	12.4	14.7	90.2
Red Lake	RL	E	10	10.9	14.8	67.6
St. Catharines	SC	D	11	12.6*	15.7*	75.7
Sarnia	Sa	D	13	15.4	18.5	111.1
Sault Ste. Marie (A)	SSM	E	12.5	15.3	19.5	119.1
Simcoe	Si	C	10	15.3	18.2	117.5
Sioux Lookout (A)	SL	E	10	13.0	17.7	90.2

TABLE 3 continued

Ontario wind data

Station Name	Abbreviation on Map	Terrain Category	Anemometer Height (m)	Annual mean wind speed (km/hr)	Annual mean wind speed at 30m height (km/hr)	Maximum gust speed (km/hr)
Southampton	So	E	10.5	10.3*	13.8*	122.4
South Bay Mouth	SB	D	24.5	15.6	16.3	101.4
Stirling	St	D	14	11.4	13.5	112.7
Sudbury (A)	Su	C	10	21.4	25.5	136.9
Thunder Bay (A)	TB	B	10	14.2	16.2	122.4
Timmins (A)	Ti	D	11.5	14.3	17.7	104.7
Toronto (Agincourt)	TA	C	13	15.4	17.6	119.1
Toronto (Int. A. Malton)	TM	D	10	15.6	19.9	135.2
Toronto (Island)	Ti	D	11.5	17.2	21.2	125.6
Trenton (A)	Tr	C	10	16.1	19.2	154.6
Trout Lake		E	10	14.8	20.1	86.9
Vineland Stn	Vi	D	10	15.0	19.1	107.9
White River	WR	E	10	8.4*	11.4*	96.6
Wiarton (A)	Wi	D	10	17.4	22.2	109.5
Windsor (A)	Wd	C	10	17.1	20.4	148.1
Winisk (A)		C	13.5	18.3	20.8	120.7

NOTE: 'A' means 'airport'. Asterisk means that the Atmospheric Environment Service considers the annual mean wind speeds to be lower than expected for the general area. Terrain categories: A - open water, all sides; B - shoreline, smooth surface; C - flat, open country; D - low woods or crops, E - heavy woods or suburbs.

SOURCE: Ministry of Energy

TABLE 4

Coefficients for converting wind speeds to different heights and between different terrains

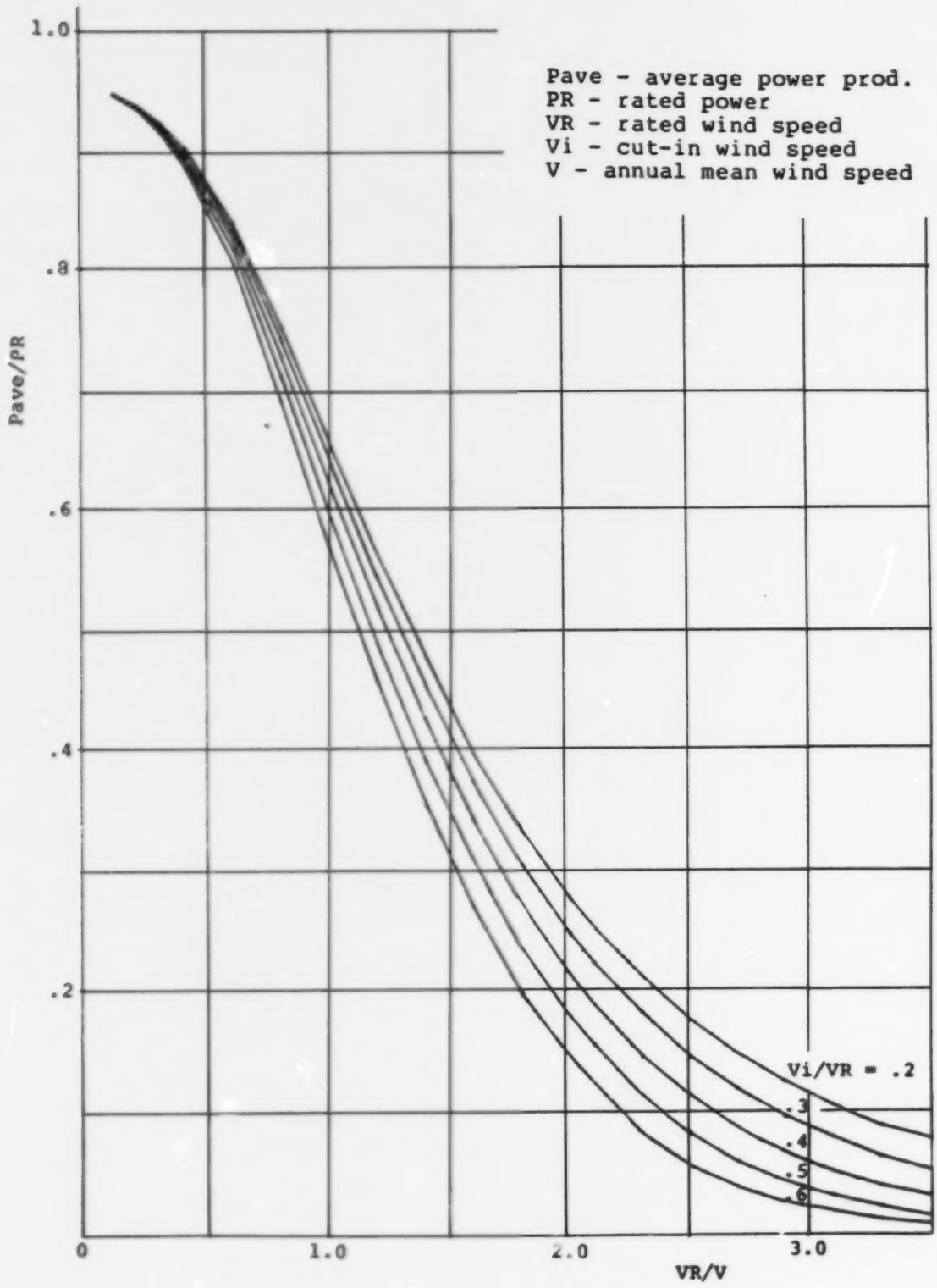
Terrain	Height in metres (feet in parentheses)					
	6(20)	12(40)	18(60)	24(80)	30(100)	40(130)
A Open water all sides	0.894	0.938	0.965	0.984	1.00	1.02
B Shoreline, smooth surface	0.824	0.896	0.941	0.974	1.00	1.04
C Flat, open country	0.773	0.864	0.922	0.965	1.00	1.05
D Low woods or crops	0.702	0.818	0.894	0.951	1.00	1.07
E Heavy woods or suburbs	0.637	0.774	0.867	0.940	1.00	1.08

NOTE: Interpolate as necessary for intermediate heights; thus in terrain C, flat, open country, the coefficient for 10 m would be 0.834.

Wind speeds are in the ratio of the coefficients. Thus if the wind at 24 metres over open water (terrain A) is 17 km/h, at 12 m over low woods (terrain D) it would be (17 X 0.818/0.984) 14 km/h.

SOURCE: Ministry of Energy

Figure 16 - Universal normalized energy curves.



Vmreq stands for 'annual mean wind speed required to produce Pa'. Now find Vmreq:

Vmreq = Vr/(Vr/Vmreq).

Next find the ratio of this speed to Vm: Vmreq/Vm. Now refer to Table 4. Select the terrain characteristic of the site, and note the height at which Vm was recorded. Let us say Vmreq/Vm for a particular machine is 1.19, the terrain is flat, open country, and the height at which Vm is recorded is 12 metres. We note from Table 4 that the coefficient for the 12 metre height is 0.864.

The Vmreq/Vm coefficient is adjusted by multiplying it by the Vm height coefficient, and the revised Vmreq/Vm is used. Thus, with a height of 12 metres, the revised Vmreq/Vm coefficient becomes 1.19 x 0.864 = 1.028. This revised coefficient indicates that the necessary tower height for this machine to produce Pa would be about 35 metres (referring again to Table 4).

Following this procedure for each machine gives a variety of tower heights that can be used as indicators of suitability. Other things equal, the lower the tower the better, especially since towers are expensive and sometimes a problem to install if very high. However, more efficient machines are usually also more expensive, and a less expensive machine on a somewhat higher tower may turn out to be preferable.

In any case, these estimates will allow the selection of two or three prime candidates, whose performance can be verified by making the more refined estimates described later.

Power Transmission Losses

The Canadian Electrical Safety Code specifies a maximum allowable voltage drop of five per cent from the point of generation to the point of end use. For distances of 30 metres or less this requirement will rarely be a problem. But for more remote siting it will have to be taken into consideration and may affect the size of components.

The formula for determining the maximum distance between wind generator and point of end-use is as follows:

$L = V/2IR,$

where L is the maximum wire length in metres;

I is the maximum current (rated power of generator in watts divided by voltage output);

V is the voltage drop in volts (0.05 x maximum generator voltage);

and R is the wire resistance per metre. To find R, first find the maximum current I then use Table 5 to find the minimum wire size and the resistance per metre.

In our example, using a wind generator to operate appliances, the voltage output is 120. In this widely applicable case the formula above ($L = V/2IR$) becomes ($0.05 \times 120/2\ IR$), that is

$L = 3/IR.$

If the maximum length L is inadequate, either I or R can be decreased - or both. Maximum current can be decreased by stepping up the voltage with a transformer and the resistance per metre can be decreased by selecting a larger diameter wire. In both cases, of course, extra expense is involved.

TABLE 5

Wire sizes with maximum current allowed by the Canadian Electrical Safety Code and the wire resistance per metre (copper wire)

Wire Size	Maximum Current (amps)	wire resistance per metre (ohms/m)
14	15	0.008412
12	20	0.005322
10	30	0.003337
8	40	0.0021
6	55	0.001345
4	70	0.00085
3	80	not available
2	100	0.000531
1	110	not available
0	125	0.000335
00	145	0.000266
000	165	0.000211
0000	195	0.000167

NOTE: Maximum allowable currents in aluminum wire are less than in copper wire. These figures are for standard T (thermoplastic) and TW (thermoplastic, weatherproof) wire.

SOURCE: Canadian Electric Code, Part 1 (Canadian Standards Association 1975) and Ministry of Energy

These considerations may well rule out some candidate wind generators: those that are unnecessarily large, or perhaps a DC generator whose voltage cannot be stepped up. Often the manufacturer can recommend such techniques as multi-phase generators and multiple wires as alternatives.

Refined Estimates: Selecting a Wind Generator

To plan and estimate the costs of a complete wind generation system we must move to a more accurate calculation of power output from specific machines. To do this a wind speed/power output curve is needed for each candidate wind generator (such as that shown in Figure 13) as well as a wind duration curve for the site (See Appendix B).

The wind duration curve is divided along the horizontal axis into 500-hour intervals. At the mid-point of each interval (250, 750, 1250, 1750 ...) the wind speed on the curve is noted. The corresponding power output is then found on the machine's power curve. The result is a list of average power outputs for all the intervals. Multiplication by 500 gives the average energy output for each interval. Summing the energy outputs gives total annual energy production by that machine at that height. This more accurate number is used to verify the preliminary estimate.

Only one wind duration curve is needed for a site (unless a more accurate one based on better data becomes possible). To find wind speeds at different heights, extrapolation coefficients calculated from Table 4 can be applied directly to the mid-point speeds and the new power outputs found immediately. (The ratio of the new height coefficient over the old height coefficient is used.)

Note that it is not enough to multiply the power by the wind speed extrapolation coefficient because power increases by as much as the cube of the wind speed, depending on the machine's power curve.

Once a generator-tower combination has been selected it is time to consider the other components of the system.

Battery Storage Capacity

Adequate Wind Speed

The first step in estimating how much storage capacity is needed is to choose the 'adequate wind speed', that is, a wind speed above which the generator alone can normally meet the demand and charge the batteries and below which the batteries must be prepared to discharge and assist the generator. There is a certain amount of choice because a higher adequate wind speed gives a wider safety margin but is more costly. An obvious lower limit for the adequate wind speed is Vi, the cut-in wind speed. Below that speed the generator will not be functioning at all and the electrical storage will be indispensable. An obvious upper limit is Vr, the rated wind speed, because for most wind generators the power levels off for wind speeds above Vr and the generator should then always meet the demand.

A logical choice for the adequate wind speed is that corresponding to the real average power demand on the machine's power/wind speed curve. This will allow the storage system to be designed to assist the generator whenever the wind speed drops below requirements for the average power demand.

An advantage with battery storage is that more batteries can easily be added to increase the storage capacity incrementally, as necessary. Thus there is something to be said for starting with a reasonable minimum safety margin, provided that a shortage of power in extreme circumstances can be anticipated and mitigated by conservation so as to be non-hazardous.

The importance of energy conservation can clearly be seen in its relation to the amount of storage capacity needed. The ability to conserve energy is not only an important backup and safety margin. It is also an alternative storage capacity, which together with the purchased and installed capacity, constitutes the total storage capacity of the wind energy system. The more you can do (in conservation) the less you have to buy (in storage capacity).

Return Time

Once the adequate wind speed is selected, an important consideration emerges: the return time, or the period of time the wind tends to stay below the adequate speed. Much greater storage capacity is required at sites where periods of inadequate wind are lengthy.

Again the best results will be found using proper measurements at the site, information probably not available at a preliminary stage. To supply this information on a general level, Environment Canada made special computations for the Ministry of Energy leading to the construction of the table in Appendix C. For several selected wind speeds, Table C.1 shows how many times a year periods of various length occur in which the wind remains at or below that speed.

The appendix shows how the table can be used to select an appropriate return time. However, the table shows a high degree of uniformity among the eight centres in central and southern Ontario. A simple rule is that return time depends only on the adequate speed, regardless of location as follows:

Adequate wind speed (km/h)	Recommended return time (days)
10	2
15	3
20	4
25	5

A return time based on these durations is a reasonable place to start. For intermediate wind speeds, return times can be interpolated; thus for an adequate wind speed of 18 km/h, a return time of 3.6 days might be adopted.

In Ontario the maximum calm periods occur in mid-summer. A user may wish to prepare a special conservative estimate of average power demand in that season (if possible incorporating an energy conservation strategy for calm periods) to see whether a significantly reduced storage capacity seems feasible.

Estimating Battery Storage Capacity

The storage capacity is estimated by the following calculation:

> Return time (days) X 24 X real average power demand = storage capacity (kWh)

For a given type of battery, find the ampere-hours rating (energy retrievable without damage) at a temperature equivalent to the coldest ambient temperature at which the batteries will be stored.

To find the total ampere-hours required, multiply the storage capacity needed (kWh) by 1000 and divide by the battery voltage.

Divide the total ampere-hours required by the battery ampere-hours rating to find the number of batteries needed.

The batteries must be connected so the total voltage matches the generator DC output rating and the voltage required for the load or the inverter.

CHOOSING A WIND/WATER PUMPING SYSTEM

The procedure for selecting the most suitable wind powered water pump system which will meet a specified demand for water is similar to that for the wind generator system.

The important determinants are again maximum power and energy; maximum power being of importance in instances where a specified flow rate must be maintained, such as for direct irrigation, and energy being determined by the total volume of water required.

Power and Energy Required

For pumping water, the following formulae apply:

Power required (W) = 0.1632 X Q X H,*

Energy required (kWh) = (0.002719 X V X H)/1000,

where Q is the maximum flow rate in litres per minute,

V is the volume of water in litres, and H is the total head in metres.

*Footnote: Mechanical energy systems are usually rated in horsepower (HP) as to power output, where 1 HP = 746 W = 0.746 kW.

What complicates these calculations is the estimate of H, total head, because it consists of the addition of two parts: the vertical distance the water has to be raised during pumping and the 'equivalent head loss'. This is a translation into terms of height stating that power is required to push the water through a pipe.

The equivalent head loss depends on a combination of factors such as diameter and length of pipe. Figure 17 provides head loss data for common steel and plastic pipe. The equivalent head loss is the head loss factor times the total length of the pipe. It is common to add 1 metre for every fitting and 4 metres for every elbow used in the pipe run.

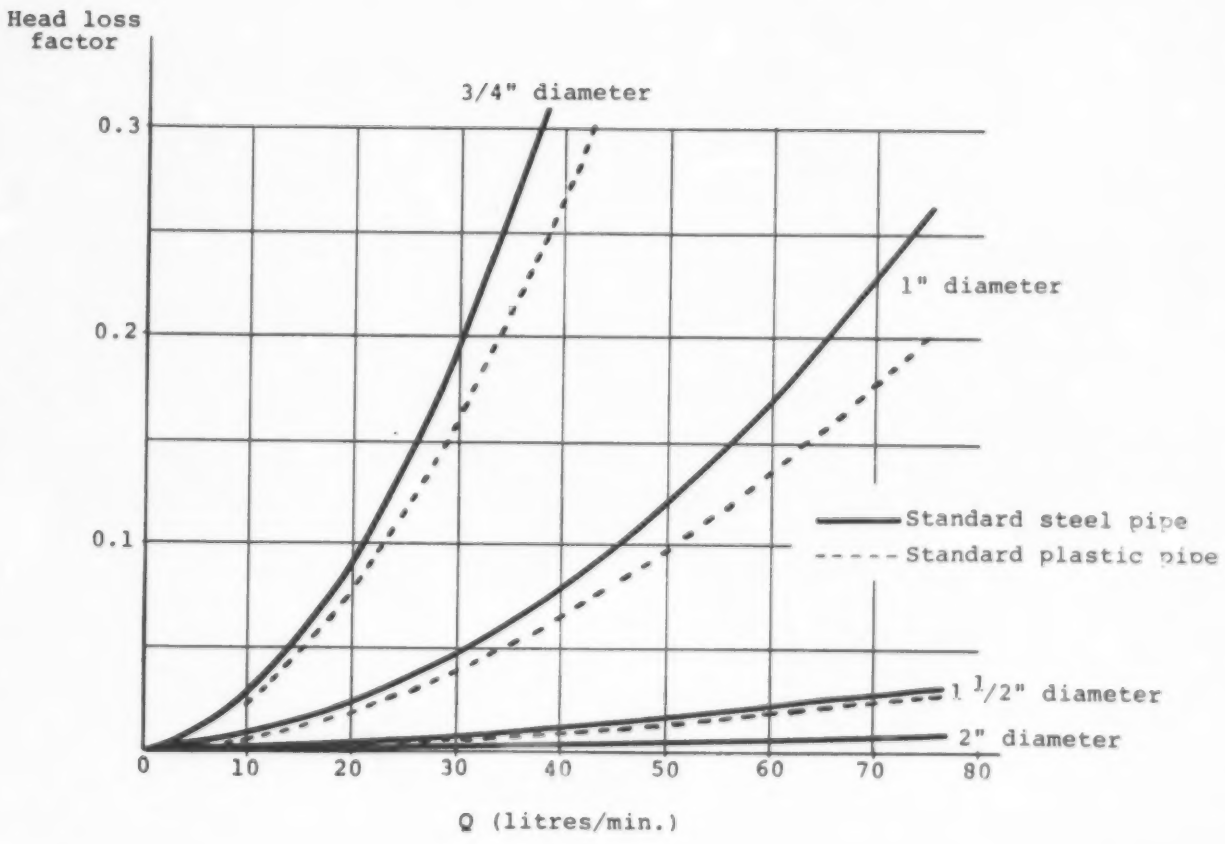
The methods introduced earlier in this chapter can similarly be employed to choose the wind pump size and tower height. Often manufacturers will provide figures for volume of water pumped for a given tower height at a specified annual mean wind speed, thus providing the user with the preliminary estimates.

Storage capacity to meet demand during inadequate winds can be determined using the same methods employed in the preceeding sections on Storage Capacity. (The stored energy is related to the volume of storage by the energy equation given above where H is the total head measured from the reservoir to the point of end use.)

ESTIMATING THE COST OF THE WINDPOWER SYSTEM

By this stage, specific examples of the basic components of the wind energy system have been identified. Their costs will be known, as well as the costs of installation. The total cost and the time it would take the system to pay for itself and start yielding a return on the investment can now be estimated.

Figure 17 - Computer for estimating the head loss factor in a wind pump system. The appropriate pipe curve is selected; a vertical from the flow rate on the horizontal axis intersects that curve; a horizontal from the intersection gives a value for the head loss factor on the vertical axis.



Three separate costs are involved: the installed cost of the whole system; the annual cost of maintenance, insurance, property taxes, loan interest and repayment; and the comparable cost of energy from present or alternative sources.

Annual Cost

Calculations of annual cost may lead to a review of the system and perhaps some modifications. They also allow a rough comparison of the cost of wind energy with the cost of energy from other sources at current prices. The benefits of using a form of energy which in itself is free and the benefits of an independent and secure energy supply must be weighed against the costs of buying and maintaining the equipment.

The system's total annual cost is the sum of the annual costs of maintenance, property taxes and insurance, and loan interest and repayment. Annual maintenance costs for components are often specified by the manufacturers at about one or two per cent. The increase in property taxes and insurance will probably be similar. The loan interest plus repayment of capital cost can be calculated with the following formula:

$$\text{annual cost} = \text{amount of loan} \times \frac{(i(1+i)^n)}{((1+i)^n-1)}$$

where i is the interest rate and n is the term of the loan in years (assuming annual payments).

If more detailed estimates are not possible, as a last resort a useful rough estimate can be made by taking 20 per cent of the total installed cost as the annual cost. Divide this amount by total annual energy consumption to give an annual cost of energy per kilowatt hour.

Cost Over Life of System and Payback Time

Estimating how long the system will take to pay for itself -- the 'pay-back period' -- is somewhat more complicated. Moreover, it is always based on a comparison with alternatives. For instance a system will pay for itself sooner when compared with the more expensive alternative than when compared with the less expensive alternative.

Life-cycle cost evaluation accumulates the total cost of the system up to any given future year and expresses that cost in present-value dollars. Consider a system with an installed cost of $10,000 and an annual cost of $2,000; the simplified life-cycle cost of that system in three years would be $16,000 ($10,000 + $2,000 + $2,000 + $2,000). But that simplified life-cycle cost rapidly becomes misleading because any payment made in the future will accrue interest earned on the money from now until the payment is made. To pay the equivalent of $2,000 in three years we need $2,000 less three years of interest. In other words, a discount factor must be applied to express future annual costs in present terms.

Call the annual cost c and the discount factor d. The life-cycle costs therefore accumulate, not as $c + c + c \ldots + c$, but as $c/d + c/d^2 + c/d^3 \ldots + c/d^n$, where d is greater than 1. (The discount factor is 1 + the discount rate which is the interest rate you would have expected to receive on the money if it were otherwise invested. For instance, if that interest rate were 12 per cent, the discount rate would be 0.12 and the discount factor d would 1.12.)

When comparing a wind energy system's life-cycle cost to those of other alternatives, the projected costs of fuel for the latter must be estimated and inflation of non-fuel items (i.e. capital, labour, etc.) must be accounted for.

On the basis of life-cycle cost, Table 6 compares a hypothetical wind-energy system to installing a connection to and using the provincial electrical grid and a diesel generator system. The discount factor used is a typical value of 1.15 and is applied in all cases. The wind system does not repay the investment compared to grid interconnection, but it starts to pay back, compared to the diesel system, after 13 years.

TABLE 6

Hypothetical life-cycle costs ($1981)

Year	Wind System	Grid System	Diesel System
1981	13980	5220	2590
2	15710	6300	4120
3	17210	7270	5630
4	18510	8140	7120
5	19650	8920	8620
6	20630	9120	10140
7	21490	9310	11700
8	22240	9510	13310
9	22880	9710	15000
1990	23450	9900	16760
1	23500	10090	18630
2	23540	10280	20610
3	23580	10470	22720
4	23620	10650	24980
5	23650	10840	27410
6	23670	11020	30020
7	23690	11200	32840
8	23710	11380	35880
9	23730	11560	39170
2000	23740	11740	42730
1	23760	11900	46580
2	23770	12070	50760
3	23780	12250	55290
4	23790	12420	60210
5	23800	12590	65550
6	23800	12750	71340
7	23810	13080	84470
8	23810	13080	84470
9	23820	13250	91890
2010	23820	13410	99960

SOURCE: Ministry of Energy

PART THREE

SAMPLE CALCULATION FOR THE SELECTION OF A WIND GENERATION SYSTEM

SAMPLE CALCULATION FOR THE SELECTION OF A WIND GENERATION SYSTEM

Power Required

A person wishes to install an independent wind energy system to operate domestic appliances. The house is situated outside Wiarton, within 15 miles of the airport weather station where the annual mean wind speed is 17.4 km/h at 10 metres above the ground (Table 3). The terrain is flat with woods and fields. An odometer rented for a year measured an annual mean wind speed of 17.5 km/h at the site. Wiarton airport data are thus assumed to be representative of site conditions since both are Terrain D.

Using nameplate specifications and Table 1, the power demand and energy consumption of the appliances were found to be as follows:

Appliances	Maximum Power (W)	Annual Consumption (kWh)
Refrigerator	300	720
Freezer	350	1080
Microwave oven	1500	180
Hot water heater	2000	3360
Lights (60W X 6)	360	360
Toaster	1100	60
Hot plate	1200	144
Television set	50	84
Clothes washer	300	96
Furnace	400	360
Vacuum cleaner	650	60

Maximum power demand (refrigerator, freezer, microwave oven, lights, hot plate, furnace, hot water heater): 6.11 kW
Total annual consumption: 6504 kWh
Average power demand (6504/8760): 0.742 kW

Because all heating elements will be wired for direct current, tne inverter will not be needed for the hot water heaters, lights, toaster and hot plate.

Inverter maximum demand (refrigerator, freezer, microwave and furnace): 2.55 Kw

Inverter total annual conversion: 2580 kWh
10 per cent efficiency loss: 258 kWh

Real total annual consumption (6504 + 258): 6762 kWh

Real average power demand: 0.772 kW

Power Produced

Average power production required (Pa): 0.772 X 1.2 = 0.926 kW
Range of turbine sizes (3-8 Pa): 2.8 to 7.4 kW
Annual mean wind speed at 10 metres (Vm): 17.4 km/h = 4.83 m/s.

	Machine 1	Machine 2	Machine 3
Pr (kW)	4.05	6.75	4.4
Vi (m/s)	2.2	5.0	2.5
Vr (m/s)	12.4	15.0	11.0
Pa/Pr	0.229	0.137	0.21
Vi/Vr	0.18	0.33	0.23
Vr/Vmreq (Figure 16)	2.23	2.47	2.25
Vmreq (Vr/(Vr/Vmrq)) (m/s)	5.56	6.07	4.89
Vmreq/Vm	1.15	1.26	1.01
Vm coefficient at 12m (Table 4)	0.818		
Vm coefficient at 10m (interpolated)	0.780		
Adjusted Vmreq/Vm (X 0.780)	0.896	0.982	0.787

Tower heights (Table 4, Terrain D)	19 m	28 m	10 m

From the tower heights required, Machine 3 seems to have a significant advantage over Machine 1, which in turn is better than Machine 2. It is necessary to examine Machine 3's performance more closely.

Refined Estimates with Wind Duration and Machine Power Curves

Since 10 metres is also the height of the Wiarton station and the terrain is similar, Wiarton's wind speed data when unadjusted can be used for this wind curve. Those annual data are as shown in Table 7.

As explained in Appendix B, cumulative hours in each column in Table 7 are plotted against the highest wind speed in the next lowest wind class. Thus the coordinates for the wind duration curve are as follows: 7902-1.34, 6293-2.68, 2967-5.37, 1399-7.61, 279-10.29, 62-12.97, 8-15.66, 1-17.90. The resulting wind duration curve (Figure 18), is segmented into 500-hour intervals from the left. At the mid-point of each interval (250, 750, 1250, 1750 ...) the wind speed is noted and the corresponding power output found on Machine 3's power curve (Figure 19). The energy output for the interval, and the results are summed to give the total annual energy production. Table 8 shows that Machine 3's annual energy production at 10 metres will be 6105 kWh, or an average power production of 0.697 kW. This is below not only Pa but also the average power demand. In spite of preliminary estimates, therefore, Machine 3 will probably be inadequate at 10 metres.

TABLE 7

Wiarton airport annual wind data at 10 m (from Atmospheric Environment Service)

Speed classes (mph)	calm	1-3	4-6	7-12	13-17	18-23	14-29	30-35	36-40	41-46	46
Speed classes (m/s)	0	0.45 - 1.34	1.79 - 2.68	3.13 - 5.37	5.82 - 7.61	8.05 -10.29	10.74 -12.97	13.42 -15.66	16.11 -17.90	18.34 -20.58	26.58
Hourly duration	394	464	1609	3326	1568	1120	217	54	7	1	0
Cumulative	8760	8366	7902	6293	2967	1399	279	62	8	1	0

TABLE 8

Machine 3 at 10 metres from wind duration curve and power curve

Mid point hours	Wind speeds (m/s)	Power Output (kW)	Energy Output (kWh)
250	10.3	3.95	1975
750	8.9	2.70	1350
1250	7.8	1.61	805
1750	7.0	1.12	560
2250	6.3	0.85	425
2750	5.6	0.60	300
3250	5.1	0.45	225
3750	4.7	0.31	155
4250	4.3	0.25	125
4750	3.8	0.17	85
5250	3.5	0.10	50
5750	3.2	0.07	35
6250	2.8	0.03	15
6750	2.5	-	-
		annual	6105 kWh

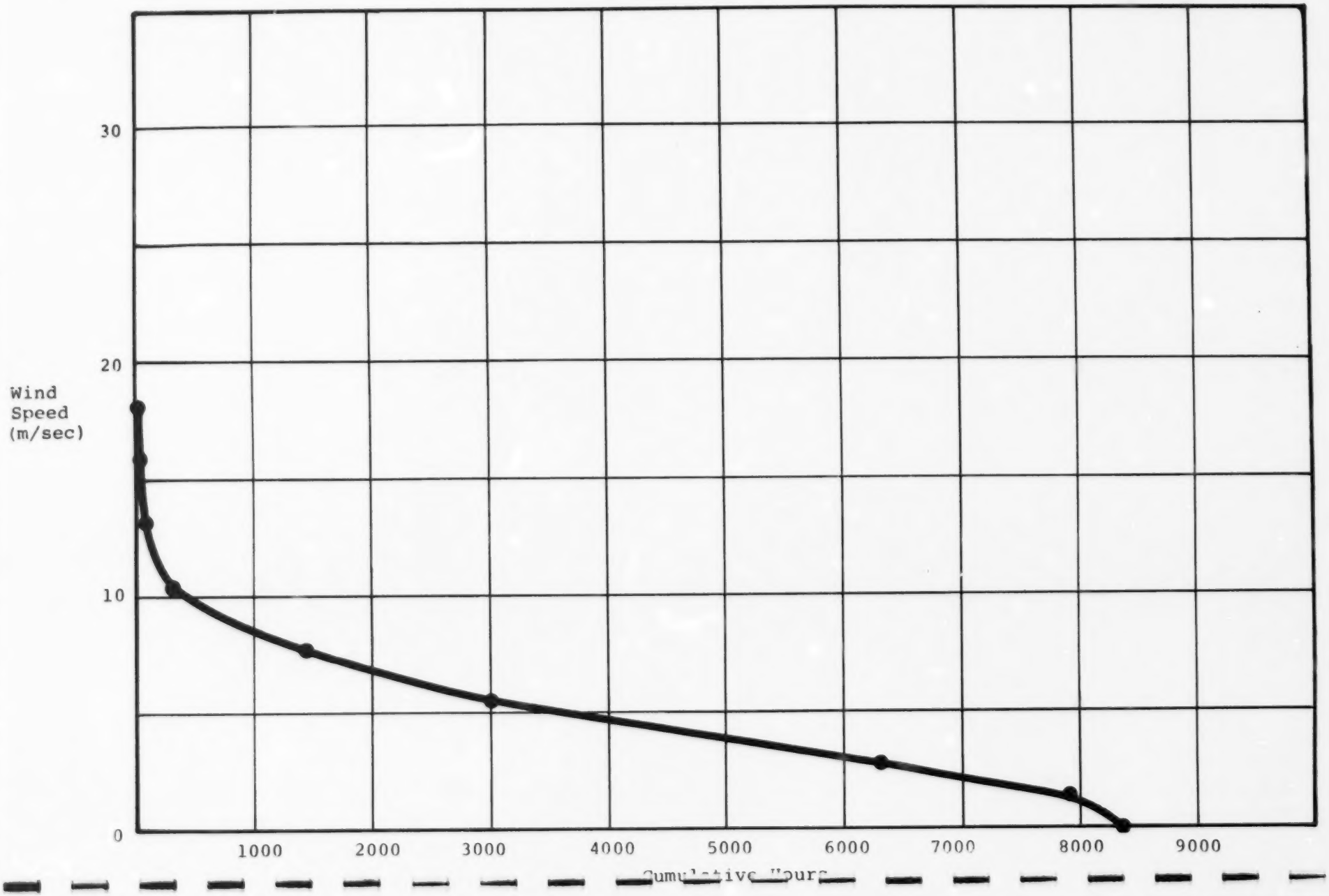
SOURCE: Figures 18 and 19

TABLE 9

Machines at 18 metres

Mid-point Hours	Wind Speed (m/s)	Machine 1 Power Output (kW)	Machine 1 Energy Output (kWh)	Machine 3 Power Output (kW)	Machine 3 Energy Output (kWh)
250	11.7	4.02	2010	4.40	2200
750	10.1	2.77	1385	3.80	1900
1250	8.9	2.08	1040	2.70	1350
1750	8.0	1.61	805	1.86	930
2250	7.2	1.21	605	1.30	650
2750	6.4	0.86	430	0.90	450
3250	5.8	0.67	335	0.68	340
3750	5.4	0.56	280	0.54	270
4250	4.9	0.46	230	0.40	200
4750	4.3	0.36	180	0.30	150
5250	4.0	0.30	150	0.20	100
5750	3.6	0.21	105	0.10	50
6250	3.2	0.15	75	0.07	35
6750	2.9	0.09	45	0.02	10
7250	2.6	0.05	25	-	-
7750	2.3	-	-	-	-
			Annual 7700 kWh		Annual 8635 kWh

FIGURE 18 Wind duration curve for Wiarton Airport at 10 meters height, based on Table 7.



Note here that the preliminary procedure using Figure 16 is based on a theoretical power curve chosen to be representative of most machines; clearly Machine 3's power curve departs from this model in providing proportionally less power at lower speeds. Moreover, machine power curves are often only an approximation -- another reason for adding a safety margin of power produced.

However, it must be seen how Machine 3 performs at 18 metres (the next available tower height) and compare it to Machine 1.

The first need is a new wind duration curve for 18 metres, which can be used for both Machines 1 and 3. To draw it, the speed ranges must be adjusted upwards by the appropriate coefficient from Table 4. In that table the extrapolation coefficient from 10 m to 18 m in low woods and crops is 0.894/0.780 = 1.14. This coefficient, if applied to the Wiarton 10 metre wind classes (Table 7), would raise the vertical axis coordinate for the wind curve by 0.14 in each case and results in a new wind curve about 14 per cent above the previous one (Figure 18). Since the wind duration curve has been used to give wind speeds at mid-point hours to calculate power output at 10 metres, there is no need to draw the new curve. Simply multiply each of those mid-point speeds in Table 8 by 1.14 to find the corresponding mid-point wind speed at 18 metres. With this new table of mid-point wind speeds, and using Figures 19 and 20, the energy production for each machine is found as described in (Table 9).

At 18 metres Machine 3's greater efficiency is obvious, with an annual energy production of 8635 kWh as against Machine 1's 7700 kWh. The real average power demand was estimated at 0.772 kW. The average power production of Machine 3 is 0.986 kW, a safety margin of 28 per cent. That of Machine 1 is 0.879 kW, a safety margin of 14 per cent.

The safety margin of Machine 3 is generous, but the generator and tower would cost 50 to 75 per cent more than Machine 1. The safety margin of Machine 1 is perhaps slightly narrow, but it is chosen because of its lower cost.

Storage Capacity

Adequate wind speed

Real average power demand is 0.772 kW. On Machine 1's power curve this output corresponds to a wind speed of 6.2 m/s, or 22.3 km/h.

Return time

The general rule for return times (see section Return Time), 22 km/h would indicate 4.4 days. When on the detailed chart of inadequate wind duration in Appendix C the wind ranges from Wiarton airport are adjusted upwards by 14 per cent (the wind speed adjustment coefficient for 10 to 18 metres is 1.14), five days is indicated. Battery storage where more capacity is possible is being used, therefore choose 4.4 days.

Capacity required

Capacity = real average power demand X 24 X 4.4 = 82 kWh.

Figure 19 - Machine 3 wind speed/power output curve

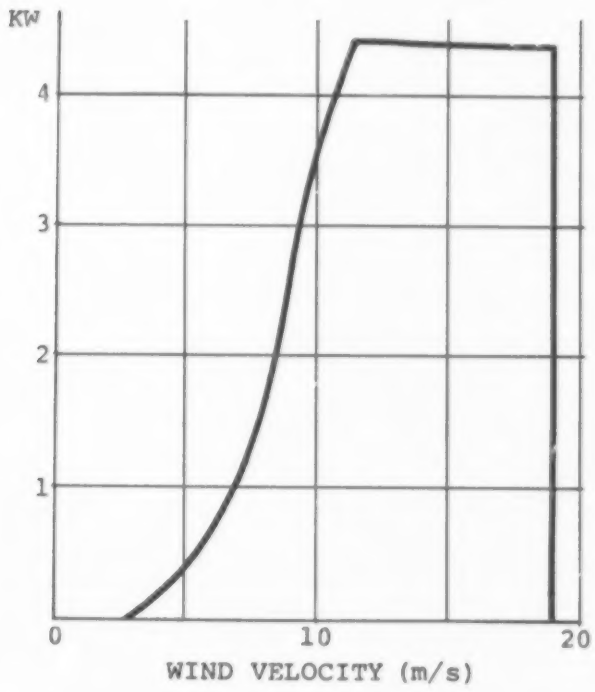
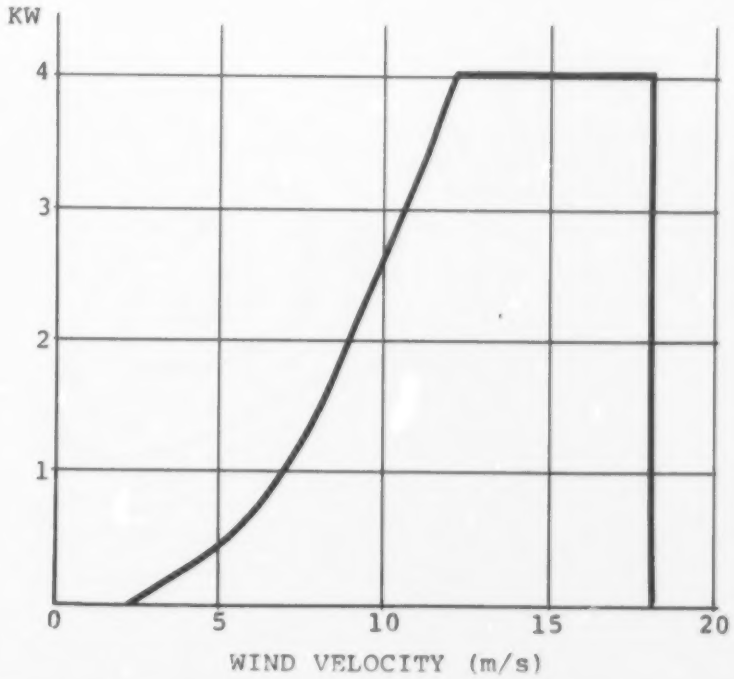


Figure 20 - Machine wind speed/power output curve



Number of batteries

Ampere-hours required = kWh X 1000/battery voltage. Therefore, the higher the battery voltage the lower the ampere-hours of storage needed.

The most common batteries are 12 volts. Therefore, ampere-hours required = 82 X 1000/12 = 6833. Ten 12 volt batteries in series will give 120 volts DC. Thus each battery must be rated at (6833/10) 683 ampere-hours at the estimated minimum ambient temperature they will be exposed to. If 10 sets of two batteries linked in parallel are used, each battery can be rated at (683/2) 342 ampere-hours.

Costs

Machine 1 costs $10,000 installed; the 18 metre tower costs $2,900 installed; a 2,600 watt stand-alone inverter costs $2,900; batteries and wiring cost $7,000. Total cost $22,800.

Annual cost

Preliminary estimate (22,800 X 0.2) = $4,560

Maintenance (average annual, manufacturers' estimates):

Wind generator 2%:	$200
Batteries 2%:	140
Tower 1%:	29
Total	$369

Increased property taxes and insurance 1%: $228

Total cost was paid for by a 10-year loan at 12 per cent interest to be paid back in 10 annual installments:

Annual interest and loan repayment costs

$$= 22,800(i(1+i)^n)/(1+i)^n-1)$$
$$= 22,800(0.12(1.12)^{10})/((1.12)^{10}-1)$$
$$= 22,800(0.12(3.11))/((3.11)-1)$$
$$= \$4,033$$

Annual cost in first ten years (369+228+4033): $4630
Annual cost after loan paid off: $597

To investigate the period compared to other forms of energy supply, life-cycle costing can be done as shown earlier.

APPENDICES

APPENDIX "A": THE WIND DURATION CURVE

WIND READINGS ON SITE

Wind speed measurements at the site over an extended period of time provide the surest basis for estimating power output available. The simplest devices are wind meters showing wind speed and direction. The disadvantage is that the values obtained must be read and logged regularly. Somewhat more sophisticated is an odometer, which measures the kilometers of wind blowing past the station. Monthly and annual mean wind speeds can be calculated by dividing the odometer figure by the elapsed time in hours. More advanced measurements are possible with chart or digital recorders which provide data suitable for the construction of a wind duration curve by showing the amount of time the wind speed remains within certain ranges.

Measurements are needed for at least three months during the windiest season of the year, but preferrably for a full 12 months. The results can be compared to local meteorological data and correlations established. For instance, it may be found that local wind speeds are systematically 2 km/h higher than at a regional meteorological station. In this case the data from that station can be used with an adjustment.

CONSTRUCTING A WIND DURATION CURVE

To construct a wind duration curve it is necessary to have data on how many hours annually the wind speed remains within a series of ranges (0-5 km/h, 6-10, etc.). There are several ways to obtain this information. The best way is with year-long continuous wind recordings at the site. The second best is with data from a nearby meteorological station - corrected if possible by a measurement of mean wind speed at the site. A last resort is to use the mean wind speed at the site and the 'universal wind duration curve' presented below.

Using speed duration data

Table A.1, Row 1, shows the data needed: the number of hours in the year the wind remains in each speed range. The first step is to accumulate the hours starting from the right-hand side (Row 2). The second step is to note the maximum wind speed from the next lower range (Row 3). Rows 2 and 3 give the co-ordinates needed to construct the wind duration curve. In this case the curve will have a horizontal axis showing cumulative hours and calibrated from zero to 8760 and a vertical axis of wind speeds in km/h calibrated from zero to 75. The points should be joined to form a smooth curve (Figure A.1). Its similarity to the universal curve (Figure A.2) is obvious. The result is an annual wind speed duration curve for the site at a given height.

The data needed to produce a wind duration curve are available from the Canadian Climate Centre, 4905 Dufferin St., Downsview, Ontario, M3H 5T4. The publication Wind for Power compiles data for a number of stations in Canada (available at the above address). When monthly wind data only are available, the annual data are found by totalling the data for 12 months.

Using the 'universal curve'

Figure A.2 shows a specially calculated universal wind speed curve directly applicable to northern Ontario sites and usable as an approximation in any part of the province. The annual mean wind speed is entered at 1.0 on the vertical axis, which is then calibrated accordingly with twice the annual mean wind speed occurring at 2.0 and interpolations made uniformly. Wind speeds at mid-point ranges (250, 750, 1250) can then be read in the usual fashion.

TABLE A-1

Wind speed classes (km/h) and coordinates for wind duration curve

SUDBURY AIRPORT	calm	1-5	6-10	11-20	21-27	28-37	38-47	48-57	58-65	66-75	75
Row 1 Hours in each wind speed class	229	273	997	3116	1859	1459	567	216	34	3	2
Row 2 Cumulative hours	8755	8526	8253	7256	4140	2281	822	255	39	5	2
Row 3 Maximum wind speed from next lower class (km/h)	-	0	5	10	20	27	37	47	57	65	75

FIGURE A.1 Wind duration curve based on Table A.1

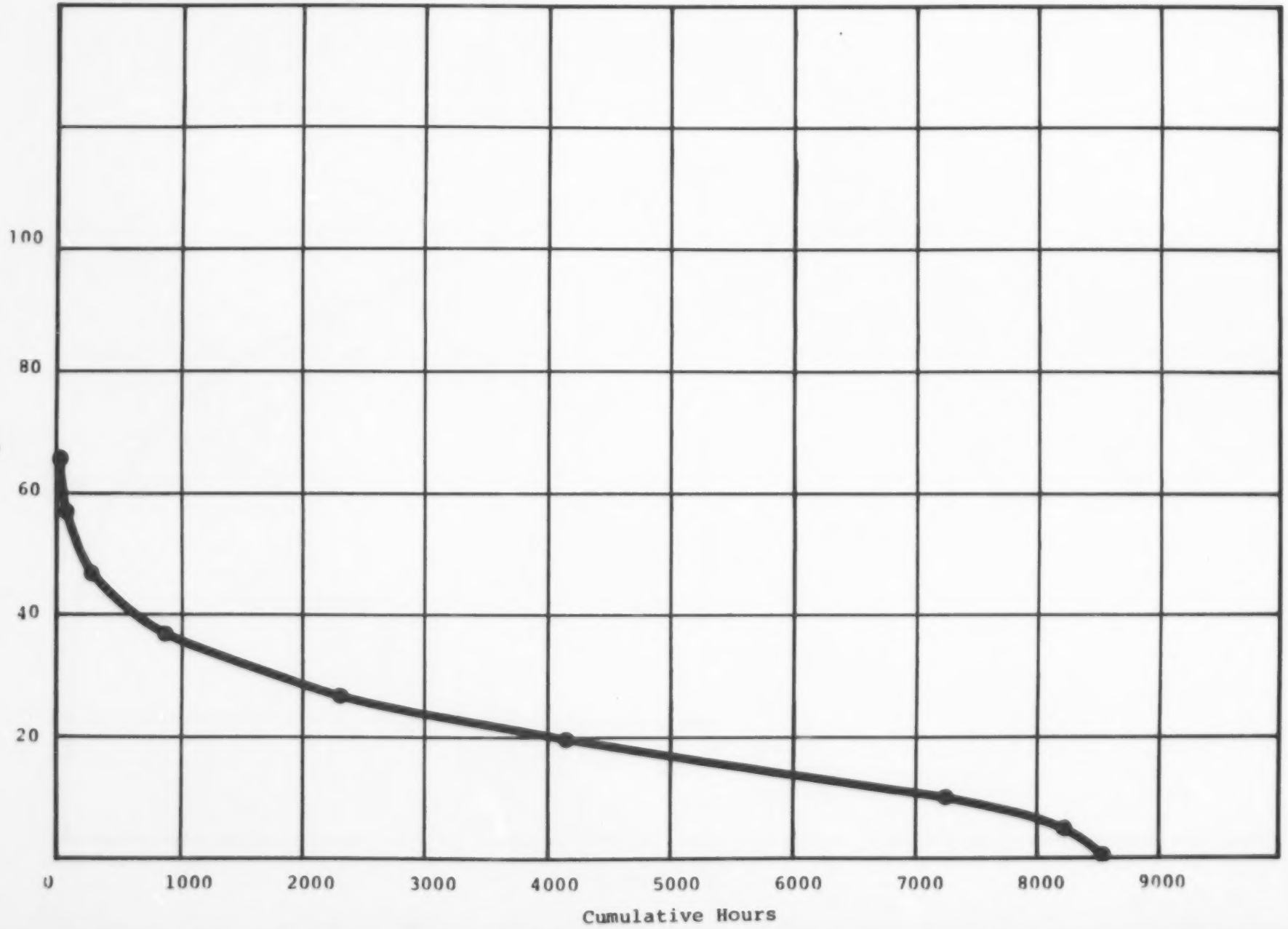
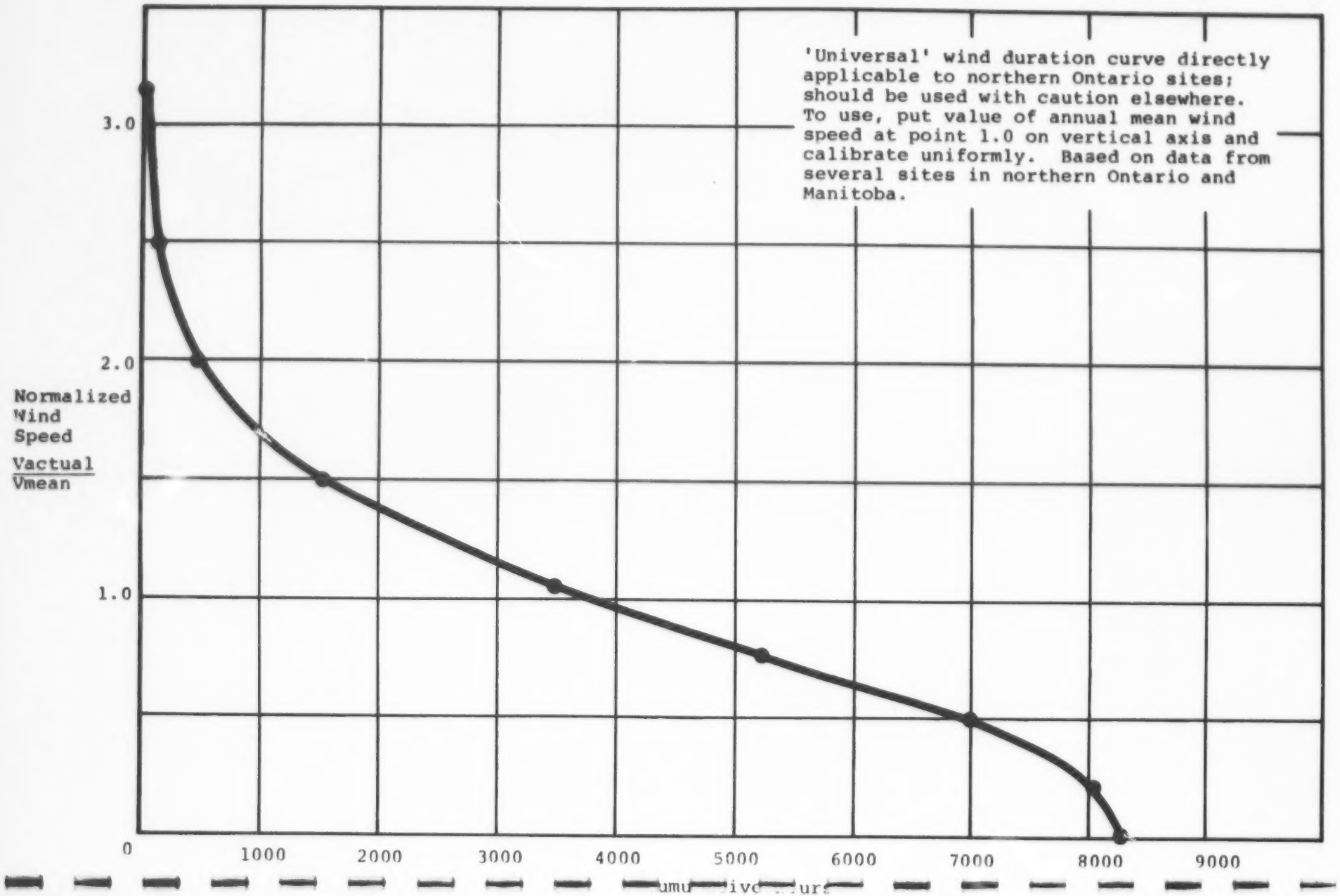


FIGURE A.2


'Universal' wind duration curve directly applicable to northern Ontario sites; should be used with caution elsewhere. To use, put value of annual mean wind speed at point 1.0 on vertical axis and calibrate uniformly. Based on data from several sites in northern Ontario and Manitoba.
3.0
2.0
1.0
0
Normalized Wind Speed
Vactual / Vmean
1000
2000
3000
4000
5000
6000
7000
8000
9000

APPLICATION OF THE WIND DURATION CURVE

When the wind duration curve for a site has been drawn, it is applied to find the power and energy output of a turbine. The first step is to divide the horizontal axis into 500-hour intervals starting from the origin (0, 500, 1000, 1500 ...). Note the mid-points of these intervals on the horizontal axis (250, 750, 1250, 1750 ...). Verticals drawn up from these mid-points intersect the wind duration curve. The wind speeds at those intersections are then listed with their corresponding mid-point intervals on a table. As outlined in the body of the handbook, the power output curve of the turbine is used to calculate the power for each wind speed and the energy output over the interval.

There is no need to draw a new wind duration curve for every height in question at a site. (This can of course be done - by calculating the conversion coefficient to the new height from Table 4, applying it to the wind speed classes in Table A.1, thus raising the co-ordinates correspondingly in Row 3 and producing a new set of curve co-ordinates. But it is the long way round.) Since we are interested in the mid-point wind speeds for the power output calculation, it is simpler to apply the height conversion coefficient (calculated from Table 4) to those wind speeds. That technique is employed in the wind turbine comparisons in the example in this handbook.

INTERVALS OF INADEQUATE WIND

The following table (A-2), based on calculations performed for the Ontario Ministry of Energy by the Atmospheric Environment Service, shows, in the left-hand column, a series of wind speed ranges from zero up to a given 'adequate' wind speed and opposite each the number of times a year the wind stays within those ranges for varying numbers of consecutive days. For instance, at the London Meterological station the wind speed stays at 14 km/h or less for one to two consecutive days 31 times a year, for two to three consecutive days six times a year, for three to four consecutive days twice a year, and for five or more consecutive days less than once a year. These intervals tend to be concentrated in the summer months.

To choose a return time, select a nearby meteorological station and an inadequate wind speed range. Consider London and 0-22 km/h. The wind does not move above the range for four to five days at a time, only four times a year on average, for five to to six days only twice a year. In general, a return time of five days would mean the system would be in danger of exhausting its storage capacity only two or three times a year, which seems adequate.

If the inadequate speed were 20 km/h we might interpolate a lower requirement of four days; for 25 km/h, five days might still be sufficient.

TABLE A-2

Annual frequency of intervals of inadequate wind.

Inadequate wind speed range (km/hr)	Length of interval in days					
	1-2	2-3	3-4	4-5	5-6	6-7
London A (10 m height)						
0-7	2	0				
0-14	31	6	2	0		
0-22	40	17	9	4	2	1
0-29	15	10	7	5	4	2
Ottawa A (10 m height)						
0-7	6	0				
0-14	41	11	3	1	0	
0-22	35	18	10	6	4	2
0-29	8	7	5	4	3	2
Sault Ste. Marie A (12.5 m height)						
0-7	3	0				
0-14	36	9	2	1	0	
0-22	44	19	8	5	3	2
0-29	18	11	9	6	4	3
Sudbury A (10 m height)						
0-7	0					
0-14	15	2	0			
0-22	41	13	4	2	1	0
0-29	34	18	10	6	4	2
Toronto International A (10 m height)						
0-7	2	0				
0-14	33	8	2	0		
0-22	38	18	9	5	3	2
0-29	15	10	7	6	4	3

TABLE A-2 (continued)

Inadequate wind speed range (km/hr)	Length of interval in days					
	1-2	2-3	3-4	4-5	5-6	6-7
Trenton A (10 m height)						
0-7	2	0				
0-14	29	6	2	0		
0-22	43	16	8	4	2	1
0-29	14	10	7	6	4	3
Wiarton A (10 m height)						
0-7	3	0				
0-14	34	7	2	0		
0-22	40	16	9	5	3	1
0-29	17	10	8	5	5	3
Windsor A (10m height)						
0-7	2	0				
0-14	29	6	2	1	0	
0-22	38	15	8	4	2	2
0-29	16	11	6	5	4	2

NOTE: 'A' means 'airport'. At all sites the calmest month is normally July or August. When using this table the wind speed ranges in the left column should be adjusted to the tower height on the site.

Ranges and frequencies between those specified can be interpolated.

SOURCE: Ministry of Energy, based on data provided by Atmospheric Environment Service, Environment Canada

APPENDIX "B": CANADIAN WIND MANUFACTURERS AND DISTRIBUTORS

Ontario

Airflow Developments (Canada) Ltd.
1281 Matheson Blvd.
Mississauga, Ontario
L4W 1R1
(416) 624-2133
Sells Sims, Anemo and Texas
Electronics wind measuring devices

C&D Batteries of Canada
150 Connie Crescent, Unit 15
Concord, Ontario
L4K 1L9
(416) 669-4400 or 667-0179
Sells lead-acid (calcium) batteries for photovoltaic and wind power applications.

Cer-a-met Manufacturing Ltd.
P.O. Box 100
Wellington, Ontario
K0K 3L0
(613) 399-2565
Distributes 1.5 Kw DC wind generators.

DAF Indal Ltd.
3570 Hawkestone Road
Mississauga, Ontario L5C 2V8
(416) 275-5300
Manufactures Darrieus vertical axis wind generators 50 KW and above for grid connection.

Efstonscience Inc.
3500 Bathurst Street
Toronto, Ontario
(416) 787-4584
Distributor of Winco Wincharger wind generators; sells wind measuring equipment.

Frederick Goertz Ltd.
1110 Sheppard Ave. E., Suite 505-1
Willowdale, Ontario
M2K 2W2
(416) 222-8167
Sells wind measuring devices and recorders.

Future Resources and Energy Ltd.
Box 1358, Station B
Downsview, Ontario M3H 5W3
(416) 630-8343
Distributor of Elektro 500 W to 10 KW propellor type, AC or DC wind generators; sells towers and batteries.

Ketchum Manufacturing Co. Ltd.
396 Berkley Avenue
Ottawa, Ontario K2A 2G6
(613) 722-3451
Distributor of Wadler Savonius wind rotor for thawing frozen ponds.

L. & R. Broadcast Services Ltd.
P.O. Box 880, 514 Chartwell Road
Oakville, Ontario
(416) 842-1492
Distributor of North Wind Power 3 KW high reliability wind generator, sells towers.

Mud River Traders and Outfitters
Mud River, Via Armstrong P.O.
Ontario P0T 1A0
Mud River 1R-22
Distributor of Jacobs 10 KW wind generator; sells towers and batteries.

Ontario Battery Services
50 Galaxy Blvd., Unit #10
Rexdale, Ontario
M9W 4Y5
(416) 675-7671
Distributor of Winco Wincharger 200 and 450 W wind generators, sells deep discharge batteries for windpower applications.

Pate Instruments Inc.
5129 Tomken Road
Mississauga, Ontario
L4W 1P1
(416) 629-1221
Sells wind speed/energy analyzers.

Renewable Dynamics Inc.
P.O. Box 1084, Station 'F'
Toronto, Ontario
M4Y 2T7
(416) 461-4433
Distributor of Air Track 3 Kw propellor type DC and grid connected wind generators.

Sommers Motor Generator Sales Ltd.
35 Elizabeth Street
Tavistock, Ontario
N0B 2R0
Distributor of Winpower 3 Kw propellor type grid connected wind generator.

Thermax Canada Ltd.
Renewable Energy Products
39 Main St.
Vankleek Hill, Ontario K0B 1R0
(613) 678-3322
Manufactures vertical axis helius rotor kit (150 W) and 200 W propellor type wind generator, low RPM generators, inverters, voltage regulators, towers.

Victrix Limited
P.O. Box 1807, 91 Duke Street
Guelph, Ontario
N1H 7A1
(519) 836-1480
Manufactures 20 kW vertical axis AC or DC wind generator.

Wellington Wind Power
Box 15
Wellington, Ontario K0K 3L0
(613) 399-3171
Manufactures 600 W, 1.5 KW, 3 KW, 5 KW, 8 KW, 10 KW and 15 KW propellor type DC wind generators; manufacturers blades and rebuilds wind generators.

Wind Turbine Co. of Canada Ltd.
21 Howard Avenue
Elmira, Ontario N3B 2C9
(519) 669-5421
Manufactures and erects Trylon lattice, self-support towers and water pumps.

Other Provinces

Crowfield Associates Ltd.
Crapand, R.R. #1
P.E.I.
(902)658-2233
Provides alternate energy consulting services, and distributes Bergey IKW wind generators.

Energy Alternatives
2 Croft Street, Box 671
Amherst, Nova Scotia B4H 1B1
(902) 667-2790
Distributor of Wincharger 200 and 450W, Bergey 1 KW and Whirlwind 3KW wind generators.

Extrawatt Inc.
220 rue Principale - C.P. 15
B.P. Hamel, St. Jean de la Lande
Beauce - Sud, Quebec. G0M 1E0
(418) 228-5999
Manufactures 1kw to 18 kw propellor type AC or DC wind generators.

Gaucher Pringle Carrier Inc.
245 Victoria Avenue
Montreal, Quebec
H3Z 2M6
(514) 935-2571
Manufactures 2KW to 38KW vertical axis DC wind generators.

Héli-o-Beauce
680, 30iéme Rue
Ville St. Georges-Ouest
Beauce, Quebec G0M 1E0
(418) 228-0049
Manufactures 1 KW propellor type AC or DC wind generators.

Macferson & Thom Alberta Ltd.
428 Moraine Rd. NE
Calgary, Alberta T2A 2P2
(403) 273-8676
Distributor of Dempster 6 to 14 ft. propellor type, piston pump water pumpers.

Merrit Windmills Inc.
Box 1374
Merrit, BC V0K 2P0
(604) 378-2552
Manufacturers 150 W and 1.5 KW vertical axis wind generators.

Nor'wester Energy Systems Ltd.
Box 7, Site 32, R.R. #12
Calgary, Alberta T3E 6W3
(403) 253-4883
Distributor of 1.2 KW Wincharger and Enertech 1.8, 5 and 40KW wind generators; provides site assessment services.

Petrosun International Inc.
2290 De La Metropole
Longuel, Quebec
(514) 670-8043
Distributor of Aerowatt propeller type 60 W to 4 KW DC wind generators.

Prairie Ditching Ltd.
418 26th St. S.
Lethbridge, Alberta T1J 3R2
(403) 327-8280
Distributor of Bowjon air lift water pumpers.

Solace Energy Centre
2425 Main Street at Broadway
Vancouver, B.C. V5T 3E1
(604) 879-5258
Distributor of Dunlite 1KW, 2KW, 5KW and 6.5KW wind generators, Soma 500 W and 1KW wind generators, Winco Wincharger 200W and 450W wind generator; sells towers, batteries, inverters, anemometers.

Wind Dynamics
Wind Power Supply Co.
208 Stockton Avenu
Okotoks, Alberta T0L 1T0
(403) 252-8761
Manufacturers 12 ft. diameter water pumpers and distributes Enertech 1.5KW, 5KW, 25KW and 40KW AC wind generators.

American Wind Manufacturers

Aeolian Kinetics
P.O. Box 1006
Providence, Rhode Island 02901
(401) 421-5033
Sells wind measuring equipment including anemometers and odometers.

Aerolite Inc.
P.O. Box 576
South Dartmouth, Massachusetts 02748
(617) 993-9999
Manufactures 6 and 10KW propellor type grid connected wind generators.

Air Track Marketing Inc.
Three Bridges Road
P. O. Box 1080
Federalsburg, Maryland 21632
(301) 754-5853
Manufactures 3KW propellor type DC and grid connected wind generators.

Bergey Windpower
2001 Priestly Avenue
Norman, Oklahoma 73069
(405) 364-4212
Manufactures 1KW and 10KW propellor type DC or AC wind generators.

Best Energy Systems for Tomorrow Inc.
P.O. Box 280
Necedah, Wisconsin 54646
(608)565-7200
Manufactures stand-alone inverters, 600 W to 12 KW.

Bowjon
2829 Burton Avenue
Burbank, California 91504
(213) 846-2620
Manufactures wind powered air lift water pumps.

Elfin Company
550 Chippenhook Road
Wallingford, Vermont 05773
(802) 446-2575
Manufactures 7.5KW propellor type AC or DC wind generators.

Enertech
P.O. Box 420
Norwich, Vermont 05055
(802) 649-1145
Manufactures 1.5 KW, 5 KW, 25KW and 40 KW propellor type, grid connected wind generators

Hummingbird Windpower Corporation
Rip Van Winkle 12306
Houston, Texas 77024
(915) 235-1735
Manufactures 4 KW propellor type, DC or grid connected wind generators.

Jacobs Wind Electric Co.
2720 Fernbrook Lane
Minneapolis, Minnesota 55441
(612) 559-9361
Manufactures 10 KW to 18KW propellor type, AC wind generators.

Jay Carter Enterprise
P.O. Box 684
Burkburnett, Texas 76354
(817) 569-2238
Manufactures 25KW propellor type grid connected wind generators.

Millville Windmills Inc.
10335 Old 44 Drive
Millville, California 96062
(916) 547-4302
Manufactures 10 KW propellor type, grid connected wind generators.

NRG Systems
P.O. Box 714
Bristol, Vermont 05443
(802) 453-4662
Sells wind measuring odometers.

North Wind Power Co.
Box 556
Moretown, Vermont 05660
(802) 496-2955
Manufactures 2 KW and 10 KW propellor type DC wind generators.

PM Windpower Inc.
P.O. Box 89
Mentor, Oklahoma 44060
(216) 255-3437
Manufactures 25KW propellor type, grid connected wind generators.

Product Development Institute
1740 Eben Road North
Holland, Ohio 43528
(419) 472-2136
Manufactures 6 KW propellor type, grid connected wind generators.

R.A. Simerl Instruments
238 West Street
Annapolis, Maryland 21401
(301) 849-8667
Sells Sims wind anemometers and recorders.

Sencenbaugh Wind Electric
P.O. Box 1174
Palo Alto, California 94306
(415) 964-1593
Manufactures 500 W to 1 KW propellor type DC wind generators.

Second Wind Inc.
2000 Massachusetts Avenue
Cambridge, Massachusetts
02140
(617) 497-1580
Sells Wind data loggers.

Solargy Corporation
17914 E. Warren Avenue
Detroit, Michigan 48224
(313) 881-5510
Manufactures lattice and monotube, free-standing and guyed towers.

Unarco-Rohn
P.O. Box 2000
Peoria, Illinois 61656
(309) 697-4400
Manufactures guyed and free-standing towers.

Whirlwind Power Co.
207 1/2 E. Superior St.
Duluth, Minnesota 55802
(218) 722-1492
Manufactures 3KW DC or grid connected wind generators.

Winco
c/o Dyna Technology
7850 Metro Parkway
Minneapolis, Minnesota 55420
(612) 853-8400
Manufactures 200 W and 450 KW propellor type DC wind generators.

Wind Master
106 K Street, Suite 200
Sacramento, California
(916) 443-0511
Distributor of 50KW propellor type grid connected wind generators built by HMZ, Belgium.

Wind Power Systems Inc.
8630 Production Avenue, Building A
San Diego, California 92121
(619) 566-1806
Manufactures 25 to 60 KW propellor type, DC or AC wind generators.

Windtech Inc.
P.O. Box 837
Glastonbury, Connecticut 06033
(203) 633-7582
Manufacturers 20 to 75KW propellor type, grid connected wind generators.

Windworks
Route 3, Box 44A
Mukwonago, Wisconsin 53149
(414) 363-4088
Manufactures 10 KW propellor type, AC or DC wind generators, sells synchronous inverters.

Winpower Corporation
1207 First Avenue E.
Newton, Iowa 50208
(515) 792-1301
Manufactures a 3KW grid connected wind generator.

APPENDIX "C": SOURCES OF INFORMATION

Windpower References

"The Wind Book" by Ian Hornby 1975
Pollution Probe
53 Queen St.
Ottawa, Ontario

An introductory book to windpower generation.

"Wind Power for Farms, Homes and Small Industry" by Jack Park 1978
NTIS
5285 Port Royal Rd.
Springfield, Virginia
22161

A handbook covering windpower generation techniques, evaluations and design.

"A Siting Handbook for Small Wind Energy Conversion Systems" by Harry & Wegley 1978
Wind Books
P.O. Box 14
Rockville Centre,
New York 11571

A comprehensive handbook on wind assessment and siting.

"Wind Power Report"
$3.00 by Browne & Warne 1975
Ontario Government
Publications Service
880 Bay St.
Toronto, Ontario
M7A 1N8

Contains information on wind generator performance, wind assessment and windpower feasibility in Northern Ontario.

"The Wind Power Book" by Jack Park, 1981
Harrowsmith Magazine
Camden East, Ontario
K0K 1J0

A small wind system designer's handbook for the semi-technical person. Also a good book for those who want to know how wind systems work.

"Windpower: For the Homeowner" by Donald Marier
Alternative Sources of Energy, Inc.
Milaca, Minnestoa
56353

A guidebook to siting and installing a wind power system.

"Windpower: A handbook on Wind Energy Conversion Systems" by V.D. Hunt 1981
Van Nostrand Reinhold Co.
135 West 50th St.
New York, N.Y.
10020

A comprehensive textbook covering technical, design, historical, and state of the art aspects of windpower generation.

Wind Data

"Canadian Normals, Vol. 3: Wind" by Environment Canada 1975
Canadian Climate Centre
4905 Dufferin St.
Downsview, Ontario
M3H 5T4

Gives monthly average wind data for all meteorological stations in Canada.

"Wind for Power" by Environment Canada
Canadian Climate Centre
Downsview, Ontario

Gives wind data in speed classes for a number of stations in Canada (for constructing annual wind duration curves).

"Hourly Data Summaries" by Environment Canada
Canadian Climate Centre
Downsview, Ontario

Hourly frequency of wind direction and speed monthly data for specific stations in Canada.

Wind Machines

"Wind Energy Sources: 1979" Issue #22, Sept. 1979

Harrowsmith Magazine
Camden East,
Ontario KOK 1J0

Gives a list of wind manufacturers and distributors with some technical data and costs, and sources of wind machine plans.

"A Guide to Commercially Available Wind Machines" by Rocky Flats Program 1978
NTIS
Springfield, Virginia
22161

Gives technical data and power curves for many wind machines.

Storage Mediums

"Energy Storage" by J. Jensen
Butterworth and co. Ltd
2265 Midland Ave.
Scarborough, Ontario
MIP 4S1

Theory and assessment related to the various storage methods.

"Energy Storage Systems" by F. Kalhammer
Scientific American,
Dec. 1979, Vol.241, No. 6
P.O. Box 5919
New York, N.Y. 10017

An overview and update of storage systems with comparative costs.

"Energy for the Home" by Peter Clegg 1975
Garden Way Publishing
Charlotte, Vermont
05445

Contains information on alternative energy sources, storage mediums, and heat pumps and supplies manufacturers' data sheets.

"How to Design an Independent Power System" By Terrance Paul, 1981
BEST Energy Systems for Tomorrow, Inc.
Necedah, Wisconsin 54646

Considers the design aspects and problems of setting up a battery storage system and back-up generator for any type of stand-alone power system. Also describes the use of various inverters.

Windpower periodicals

"Renewable Energy News" (monthly)
REN Publishing Ltd.
P.O. Box 4869, Station E
Ottawa, Ontario K1S 5J1

A newspaper covering developments in renewable energy technology and issues in Canada and abroad.

"Alternative Sources of Energy" (bi-monthly)
Alternative Sources of Energy Inc.
107 S. Central Avenue
Milaca, Minnesota 56353

A magazine containing articles of interest on alternative energy sources including wind power.

"Wind Energy Report" (few per year)
P.O. Box 64
Rockville Centre
New York 11571

A report containing articles on present status of windpower research and development and installations. Centres on large-scale installations.

APPENDIX "D": METRIC CONVERSION TABLE

Length	1 foot (ft.) = .3048 metre (m) 1 mile (mi.) = 1.609 kilometers (km) 1 km = 1000 m
Area	1 ft^2 = .0929 m^2 1 acre = 4047 m^2
Volume	1 ft^3 = .02832 m^3 1 gallon (gal.) (Imperial) = .004546 m^3 1 m^3 = 1000 litres (l.) 1 acre ft. = 1234 m^3
Mass	1 pound (lb.) = .4536 kilogram (kg.) 1 ton = 1016 kg. 1 kg. = 1000 grams (g.)
Density	1 lb/ft^3 = 16.02 kg/m^3
Speed	1 mi/hr (MPH) - .447 m/sec. 1 m/sec. = 3.6 km/hr.
Power	1 watt (W) = 1 Joule/sec. (J/sec.) 1 horsepower (HP) = 745.7 W 1 kilowatt (KW) = 1000 W
Energy	1 BTU = 1055 J = .0002931 kilowatt.hours (kwh) 1 KWH = 1000 wh
Temperature	$°C = \frac{°F - 32}{1.8}$ F = Fahrenheit C = Centigrade (Celcius) $°K = °C + 273$ K = Kelvin
Time	1 year = 8760 hours 1 month = 30.4 days = 730 hours

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